TECHNICAL REPORT

AN EVALUATION OF A COMPUTERIZED NUMERICAL WAVE PREDICTION MODEL FOR THE NORTH ATLANTIC OCEAN

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A B S T R A C T

Procedures used to evaluate a computerized numerical wave prediction program are described. Since the model input is the forecast wind, periods corresponding to known wave growth and decay at Ocean Stations 'A', 'I', 'J', and 'K' and at ARGUS ISLAND Tower were selected to evaluate its response. Wave forecasts for 12, 30, and 36-hour periods are compared statistically to Tucker meter and the ARGUS ISLAND wave staff measurements. Comparisons of results using both U. S. Weather Bureau and Fleet Numerical Weather Central wind fields as input data are shown. The evaluation indicates that the forecasts are within a reasonable degree of accuracy for forecast intervals up to 36 hours. This basic model which represents another step forward in the state-of-the-art is expected to offer a considerable improvement in wave forecasts during the next decade.

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FOREWORD

The Navy and combat forces have had continuing requirements for improved forecasts of ocean surface waves. The needs expressed during World War II provided a strong motivating force which led to the development of wave forecast techniques which produced consistent results. Techniques developed by Sverdrup and Munk and published in 1947 as H. O. Publication No. 601 provided forecasts of significant wave heights and periods. Later adaptation of random processes to the study of ocean waves resulted in the spectral forecast technique described in H. O. Publication No. 603. A recent outgrowth of the spectral technique has been the development of numerical computer models to forecast the directional wave spectrum. This new capability offers an opportunity to develop shallow water wave forecast models and to automate ship routing techniques. The purpose of this study is to evaluate this recent application of numerical techniques to computerized wave forecasts.

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INTRODUCTION

In 1922, Lewis F. Richardson, an Englishman, published his book entitled Weather Prediction by Numerical Process. His manual procedures for numerical weather predicting were impractical, however, because of the length of time required to produce the desired results. Some twenty years later, the advent of high speed electronic data processors made numerical methods much more practical. After many trials and tribulations, somewhat reliable numerical weather predictions on a limited basis and for the upper atmosphere became available by the mid-1950's. During the past decade rapid advances have been made, both in numerical theory and in the sophistication of electronic data processing equipment. Presently, numerical weather predictions are routine over vast areas of the globe with constant improvements being made as researchers attack the various problems.

Following a somewhat analogous pattern, the problem of ocean wave prediction has also been attacked with considerable success during the past two decades. Ocean wave predictions received serious consideration beginning in the early 1940's after certain relationships among wind speeds, wind directions, and fetch lengths on water surfaces had been empirically determined. During the 1950's prognostic wave charts, giving wave heights and directions over the oceans, were being produced manually at certain weather centers for ship routing and operations. It was soon realized, however, that the subjectivity and tediousness of these manual forecasts required a more practical method for obtaining them.

By the early 1960's raw weather data from land and ship observations were being fed into electronic computers to produce synoptic and prognostic charts of surface pressure. From these the winds over the oceans were computed and used as computer inputs to produce synoptic and prognostic charts of wave heights and directions. At first, these forecasts were limited in their application because they yielded only the wave heights and directions instead of the more sophisticated and realistic ocean wave directional spectra. The necessity for the spectral approach to wave forecasting soon became evident.

The Naval Oceanographic Office was given the task of preparing a wave spectra climatology for the North Atlantic Ocean in 1961. It was immediately recognized that the immensity of this task required the use of electronic computers and numerical procedures. Accordingly, contracts were let with private research groups qualified and experienced in

the use of computers and ocean wave fields to produce realistic wind fields over the oceans from synoptic weather data, and from these to compute wave spectral data with the proper growth, propagation, and decay. The Travelers Research Company developed a numerical technique to convert pressure fields to wind fields and New York University developed the numerical wave forecasting model. The research performed under these contracts has been reported by Bunting (1966).

From the initial effort leading to the preparation of a wave spectra climatology of the North Atlantic Ocean it was observed that the two basic requirements for providing realistic ocean wave data were: (1) an accurate representation of the low level wind fields and (2) a spectral wave forecasting model which properly represented the wave growth, propagation, and decay with varying wind speeds, durations, and fetch length. This wave model which in its present form uses the Pierson-Moskowitz spectrum has more recently been modified to include wave growth functions developed by Inoue. Undoubtedly, there will be many future improvements made in both these requirements as further experience is gained. Even as this report is being written, such changes are being included in the development of a model for the North Pacific Ocean. These include improvements in both the wind field analyses and the spectral wave forecasting models. The improvements in the wave model are essentially the inclusion of the Inoue wave growth functions and extensive refinements in the grid system. A report on the results of these changes will be made following the completion of the work.

METHOD

Until the wave hindcasts for the North Atlantic Ocean were completed in 1965, to our knowledge, no attempt had been made to use wind analyses to specify ocean wave spectra over oceanic scales through the use of computers. These hindcasts which constitute a wave climatology were based on synoptic weather data continuously updated at six hourly intervals using ship wind reports.

Since evaluations indicated that these hindcasts yielded relatively satisfactory wave spectra (Moskowitz, 1967), the next step forward was to attempt forecasting wave spectra from prognostic sea-level pressure fields and computed winds from these fields. After considerable planning, it was decided to use the "real time" synoptic and prognostic meteorological data as supplied by the Fleet Numerical Weather Facility (FNWF) at Monterey, California and by the United States Weather Bureau (USWB) at Suitland, Maryland as the basis of a prognostic wave-spectra evaluation program.

Although this represented a duplication of data, it provided a comparison between two different prognostic techniques as well as providing fill-ins for missing data in either of the two sets of data. The duplication procedure was found to be desirable in the operational test program since there were several occasions of missing data in one or the other sets.

The "real time" operational test program which was started in the summer of 1966 (17 August 1966) continued until 11 March 1967, a total of almost seven months. Data transmissions of sea surface pressures and observed ship reports for six-hourly synoptic times and for six-hourly prognostic times were made by a dataphone link from Monterey, California and Suitland, Maryland to New York City. The transmitted data were used at New York University as the input for data processors to give six-hourly synoptic and prognostic directional wave spectra for periods up to 36 hours. Preliminary detailed reports have been given by Moskowitz (1966, 1967).

For each six-hourly synoptic time, a first-guess wind field analysis was made based on either the FNWF or the USWB meterological surface pressure field. In both sets of data the "surface" wind was taken to be the wind at the 19.5 meter level since the wave forecasting model was formulated from the recorded wind observations of the Ocean Weather Ships (OWS) which have anemometers at this elevation. The first-guess wind fields were then modified by using all the available ship wind measurements corrected to 19.5 meters, so that the wind analyses could be made as accurately as possible. The shipboard wind estimates were used when measurements were not available. The data, however, were weighted according to a predetermined priority scheme. A relatively small error in the wind speed can make fairly large errors in the forecasted wave spectra, hence great care must be taken in constructing the wind field. For the prognostic analyses, of course, no ship observations were used.

The wave spectra output began with the computations of several days of hindcasts up to the 0000Z analysis for the day on which the prognostic spectra were to be made. This up-dating procedure was found to be essential in order to allow the model time to build up realistic wave spectra. The six-hourly prognostic data were made on a daily basis beginning at 0000Z for a total of 30 hours or for five separate forecasts for the FNWF input and for 36 hours or six separate forecasts for the USWB input. Each wave spectrum included the following: (1) date, (2) time, (3) gridpoint number, (4) wind speed, (5) wind direction, (6) 180 spectral components in 30-degree intervals of the compass and 15 intervals of frequency, (7) the sums of each of the 15 frequency intervals for all directions, and (8) the computed significant wave

height. Spectra were computed for all 519 gridpoints over the North Atlantic Ocean at locations shown in Figure 1.

The gridpoint numbers and locations for which complete spectral data were printed out at each forecast time were as follows: number 20, corresponding most nearly to the location of OWS A; number 36, corresponding to OWS I; number 72, OWS J; number 142, OWS K; and numbers 229, 230, 259, and 260 corresponding to the four nearest gridpoints to Argus Island (located approximately 25 miles southwest of Bermuda). The locations of all these gridpoints, together with the locations of the OWS stations and Argus Island, used in the evaluation, are also shown in Figure 1.

To evaluate the New York University wave-spectra data obtained by automated methods, wave meter records were acquired for four OWS locations, Weather Adviser at stations I and J, Weather Reporter at stations J and K, and FRANCE II at station A and K, plus the wave staff records from Argus Island. The wave-spectra data chosen for evaluation were those for three days in December 1966, for two days in February 1967, and for three days in March 1967. These three periods of data were chosen because an examination of the synoptic surface weather charts showed considerable storm activity which should be representative of adverse wave conditions in the eastern North Atlantic. A description of the synoptic weather conditions for each of the periods is given in the Appendix. Figures A-1, A-2, and A-3 of the Appendix show the surface synoptic weather charts as analyzed by the National Meteorological Center for 0000Z 6 December 1966, 0000Z 28 February 1967, and 0000Z 6 March 1967, which correspond to the times of maximum wave heights during each of the three periods of data. Table I shows the observed weather and the wave heights at the various OWS locations and at Argus Island.

WAVE RECORDS

Each of the wave meter records and the Argus Island wave staff records were digitized manually to a time series which contained 800 to 1440 points at time intervals of one or one and a half seconds depending on the scale of the wave record. The manually read amplitudes were punched on cards and computer processed to yield wave spectra containing 60 to 90 lag points over the frequency range from zero to 3.14 radians per second. The method followed for obtaining the spectral estimates was the same as that followed by Moskowitz, Pierson, and Mehr (1962).

The computed spectral estimates from the wave records were next plotted on graph paper for lag numbers from 4 to 32, corresponding to radian frequencies from 0.14 to 1.1117 radians per second. The units of energy density were shown

in feet squared-seconds. The time-corresponding forecasted wave spectra of New York University were then plotted in histogram form on the same graphs for lag numbers 6.5 to 29.5 for 14 different frequency bands. Thus, visual comparisons could be readily made between the wave-record estimated spectra and the computed prognostic spectra obtained from the meteorological data. Comparisons were also made of the wave-record and prognostic significant wave heights as well as the observed and computed prognostic wind directions and speeds. By these comparisons a reliable evaluation is believed to be possible.

DATA

Two sets of data were used: (1) the standard of comparison obtained from the wave records and meteorological observations of the weather ships and Argus Island; (2) the data to be evaluated which were generated on the New York University CDC 1604 computer in the form of two sets (USWB and FNWF) of prognostic wave spectra and wind conditions. The significant wave heights for both the standard and the prognostic data were computed from the respective wave spectra. Although the forecast wave spectra were given in the directional form to twelve 30-degree ranges, no use was made of these since the wave records were all one-dimensional allowing no comparisons of the directional spectra as prognosticated. Therefore, only the non-directional total energy versus frequency spectra were used in this evaluation.

A total of 75 different wave records were used for making evaluation comparisons with 190 prognostic wave spectra at 6, 12, 18, 24, 30, and 36-hourly periods. Table II shows a breakdown of the number of prognostic wave spectra for both the USWB and FNWF inputs in each of the six-hourly intervals at the five locations where comparisons were made. Table III is a summary of the more important factors concerning the wave record data from the wave meters on the three weather ships and from the Argus Island wave staff.

RESULTS AND DISCUSSION

The results of the data evaluation are presented in graphic and tabular form. Figures 2 through 5 present graphic comparisons of the predicted and observed significant wave heights with time for the USWB input data at the five different locations from which wave observations were obtained. Figures 6 through 9 give the same comparisons of wave heights for the FNWF input data. Note that for both sets of data the observed significant wave heights are graphed but the 5 and 95% confidence levels are also shown for each value by the vertical line. Table IV presents in tabular form the significant wave heights at the various stations for the analyzed wave meter or wave staff data and the automated predicted wave heights at the various corresponding gridpoints. For the wave meter

or wave staff data, the columns headed "lower and upper limits" are the wave height values for the 5 and 95% confidence levels shown graphically as vertical lines through the values on Figures 2 through 9. The "long range" columns under the predicted wave heights are the predicted values for the 30 or 36-hourly forecasts at the times of 0600Z and 1200Z, respectively. Table V gives the forecast intervals for each of the 6-hourly times.

Figures 10 and 11 show two scatter diagrams for wave height, one for the USWB input and the other for the FNWF input. These figures disclose the bias for the observed to predicted wave heights to be -1.6 feet and the RMS error ±6.2 feet for 124 observations using the USWB input; for the FNWF input the bias and RMS error are slightly less, +0.4 feet and ±5.1 feet, respectively, for 66 observations. Bias as used in this report is the average of the differences between the observed and predicted values. RMS values were computed by taking the square root of the average of the square of the differences between the observed and predicted values. Note that on Figures 10 and 11 the central diagonal line represents perfect correspondence between predicted and observed wave heights. The vertical distance from this line represents the plus or minus bias for each observation depending on whether the plot lies above or below the central diagonal. The diagonals labeled RMS show the positions on the graphs of the computed RMS errors for each figure.

In addition to evaluating the wave height data, a similar statistical analysis was made of the wind directions and speeds. Table VI shows the observed wind directions and speeds together with the machine predicted values for the same times at the same various forecast intervals as shown in Table V. It should be realized that there is a discrepancy between the locations of the observation stations and the gridpoint locations used in the evaluation as indicated on Figures 2 through 9. The effect of this discrepancy on both the wave heights and the winds was not determined in this evaluation.

Scatter diagrams for the wind directions, using the two different inputs, are shown in Figures 12 and 13. Figures 14 and 15 are scatter diagrams for the wind speeds, using the two different inputs. For the wind directions, the USWB input produces slightly better results with a bias of +46 degrees and an RMS error of ±75 degrees as against a bias of +52 degrees and an RMS error of ±78 degrees for the FNWF input. A positive bias indicates that the predicted winds veered from the observed directions. The analysis of the wind speeds discloses very little difference between the two inputs. There is a bias of -5 knots and an RMS error of ±10.1 knots for the USWB input as against a bias of -4 knots and an RMS error of ±10.5 knots for the FNWF input.

Tables VII and VIII give a breakdown of the statistical analysis for each forecast interval and for each OWS location and Argus Island. In some examples, the number of observations is not large enough to be statistically valid, hence conclusions cannot be drawn from these tables for all categories. Table IX presents a side by side comparison of each station's statistical analysis for the USWB and FNWF inputs, together with various combinations and a final summation of all the observations. The combined statistical analysis, showing the bias for significant wave heights to be -1.2 feet and the RMS error to ±5.8 feet, comes within an acceptable value when consideration is given to the fact that a sampling variability in the average observed significant height of about 10% is built into the statistical analysis as noted by Pierson and Tick (1965).

The concluding evaluation data are shown in Figures 16 to 37. The machine predicted frequency-amplitude wave-spectra histograms are superimposed on the computed wave meter or wave staff spectra, as given by the equipment on the OWS station or at Argus Island. If there is good correlation between these two spectral curves, then certainly the predicted wave spectra are acceptable. In choosing samples for this report, the procedure was to select examples by visual inspection of: the greatest correlation for each station location without regard to the input or the forecast interval (Figures 16 to 20); the greatest correlation for each forecast interval without regard to the input or the station (Figures 21 to 26); and (Figures 27 to 31 and 32 to 37) the least correlation in each of the same two categories. In choosing the greatest and least correlation samples, the significant height correlation was considered with other factors being equal in order to select the most appropriate examples. The chosen representative set of samples has observed wave heights from 3.4 to 36.4 feet with the majority between 10 and 30 feet. The observed and predicted wave heights are shown on each figure as well as the date, time, forecast interval, and location.

An inspection of Figures 16 to 20 shows that even the greatest correlation samples for station A and Argus Island could be improved considerably; whereas, the correlation samples for stations I, J, and K coincide quite closely. The poor correlations for station A and Argus Island may be the result of the station locations. Both stations are relatively near the boundaries of the gridpoint network with respect to the prevailing winds.

The numerical procedures normally would tend to be least accurate in these regions since the propagational effects would not be so accurately projected there as at stations I, J, and K which have a much wider expanse of water in the western semicircle. Furthermore, at station A the location is such that the paths of the low pressure centers are to the south of or possibly very close to the station. The winds would be very much more irregular there than for the other three OWS locations so that a slight discrepancy in the predicted path and speed of the low

center would result in large wave-spectra errors. Since the wind speeds at station A have by far the largest bias and RMS error compared with stations I, J, and K (−13 and ±17 knots, respectively, versus −3 to −7 and ±8.5 to ±12.3 knots), the discrepancies in the wave spectra would seem to be caused by miscalculations in the wind field rather than by any fault with the wave-spectra procedure. This points up the fact that the automated numerical forecasting of wave spectra can be no better than the capability of making accurate wind-field predictions.

CONCLUSIONS AND RECOMMENDATIONS

1. The evaluation of the automated numerical wave-spectra prediction program shows that the procedure is feasible and that it produces results which are within a reasonable degree of accuracy with the present state of the art.

2. The evaluation indicates that there is need for improvement in predicting surface wind fields over ocean areas and that the reliability of wave-spectra predictions closely follows the reliability of wind-field forecasts.

3. The evaluation discloses that there is no great difference in the accuracy of the prognoses of the two different inputs. If it were necessary to decide between the two, the evaluation suggests that the FNWF might be slightly superior, although this could be due to the maximum forecast interval being only 30 hours for the FNWF input as against 36 hours for the USWB input.

4. The evaluation reveals some remarkably good correlations between the predicted and the observed wave spectra. On the other hand, for station A and Argus Island the entire set of predictions could be considered as practically a "bust". Some reasons for this were listed in the preceding discussion section.

5. It is believed the evaluation gives ample proof that the automated numerical wave-spectra predictions would be valuable for operational use in most areas of the North Atlantic Ocean and that this procedure should now take precedence over the less sophisticated automated and manual methods.

6. As refinements in wind-field forecasting and in wave-spectra models become available, they can be readily adapted into the automated numerical procedures evaluated in the report, resulting in continuous future improvements in the wave-spectra predictions.

TABLE I

OBSERVED WEATHER AND WAVE HEIGHTS AT VARIOUS STATIONS

		STATION I			STATION K			ARGUS ISLAND		
DATE	TIME	WINDS DIR KTS	SFC PRESSURE MB	WAVE HEIGHTS FT	WINDS DIR KTS	SFC PRESSURE MB	WAVE HEIGHTS FT	WINDS DIR KTS	SFC PRESSURE MB	WAVE HEIGHTS FT
1966 4 DEC	12	220 — 27	1003.3	9.8	CALM	1029.8	9.2	335 — 27	1022	10.5
	18	220 — 33	995.3	15.9				330 — 22	1024	9.2
5 DEC	00	270 — 46	988.7	20.6	120 — 6	1030.7	8.3	015 — 13	1024	7.5
	06	260 — 38	995.1	24.2						
	12	240 — 40	995.7	31.6	250 — 12	1031.9	7.5	340 — 18	1024	11.8
	18	260 — 45	992.2	36.4				360 20	1024	10.1
6 DEC	00	290 — 43	996.0	35.7	300 — 16	1031.0	4.8	015 — 19	1023	8.1
	06	280 — 48	1000.1	35.0						
	12	280 — 30	1005.1	34.0	270 — 18	1031.4	6.3	355 — 13	1023	7.4
	18	270 — 30	1008.8	29.0				005 — 18	1023	6.1
7 DEC	00				310 — 18	1031.4	16.8	005 — 18	1023	5.5
	06									

		STATION A			STATION J			STATION K		
1967 27 FEB	00	050 — 29	979.3	17.2	260 — 18	988.9	12.7	200 — 20	1014.3	12.0
	06				240 — 34	980.7	14.1			
	12	350 — 22	977.5	14.2	250 — 30	985.1	17.5	230 — 27	1009.1	12.5
	18				270 — 43	984.0	20.8			
28 FEB	00				280 — 41	990.2	31.0			
	06				290 — 30	1001.6	25.5			
	12				260 — 28	1010.0	19.5			

		STATION A			STATION J			STATION K		
1967 4 MAR	00	050 — 47	972.5	19.4	240 — 48	998.1	17.7	CALM	1020.0	9.0
	06	010 — 34	973.9	21.5	230 — 35	1002.9	27.5	270 — 5	1018.4	8.2
	12				250 — 28	1004.6	22.9	260 — 11	1018.5	7.1
	18				240 — 27	1005.0	29.2	330 — 18	1020.0	8.7
5 MAR	00	360 — 27	983.5	22.4	230 — 26	1006.0	28.5	290 — 10	1023.4	13.4
	06				200 — 14	1003.1	21.7	260 — 10	1024.6	15.2
	12	350 — 18	989.0	19.6	210 — 42	992.4	24.4	240 — 15	1026.4	13.2
	18				220 — 55	988.4	30.3	210 — 22	1025.1	16.2
6 MAR	00	030 — 8	991.8	14.1	260 — 40	1005.9	32.3	220 — 20	1025.4	16.5
	06				200 — 15	1006.4	22.1	210 — 23	1022.1	15.6
	12	120 — 4	994.5	11.7	110 — 14	997.2	17.1	190 — 23	1019.3	15.3
	18				030 — 18	985.8	14.0	210 — 27	1014.1	15.5

TABLE II

NUMBER OF PROGNOSTIC WAVE - SPECTRA SAMPLES

LOCATION	INPUT	6-HRLY	12-HRLY	18-HRLY	24-HRLY	30-HRLY	36-HRLY	TOTAL
A	USWB	0	4	0	4	0	4	12
	FNWF	0	4	0	4	0	0	8
	TOTAL	0	8	0	8	0	4	20
I	USWB	2	3	3	2	2	3	15
	FNWF	0	0	0	0	0	0	0
	TOTAL	2	3	3	2	2	3	15
J	USWB	5	5	4	5	5	5	29
	FNWF	5	5	4	5	5	0	24
	TOTAL	10	10	8	10	10	5	53
K	USWB	3	7	3	7	3	7	30
	FNWF	3	4	3	4	3	0	17
	TOTAL	6	11	6	11	6	7	47
AR. IS.	USWB	7	6	6	6	7	6	38
	FNWF	4	3	3	3	4	0	17
	TOTAL	11	9	9	9	11	6	55

SUMMARY

LOCATION	INPUT	6-HRLY	12-HRLY	18-HRLY	24-HRLY	30-HRLY	36-HRLY	TOTAL
ALL SHIPS	USWB	10	19	10	18	10	19	86
	FNWF	8	13	7	13	8	0	49
	TOTAL	18	32	17	31	18	19	135
ALL SHIPS & AR. IS.	USWB	17	25	16	24	17	25	124
	FNWF	12	16	10	16	12	0	66
	TOTAL	29	41	26	40	29	25	190

TABLE III

WAVE RECORD DATA SUMMARY

ITEM	UNIT	OWS WEATHER ADVISER	OWS WEATHER REPORTER	OWS WEATHER REPORTER FRANCE II	ARGUS ISLAND
STATION		I J	K	K A	
DATES		DEC FEB MAR	FEB MAR	DEC FEB MAR	DEC MAR
NUMBER RECORDS		10 19	14	6 8	18
RECORD DURATIONS	MINUTES	30	30	20	20
SAMPLE TIME INTERVAL	SECONDS	1.25	1.25	1.50	1.00
AV. NO. OBS. PER RECORD		1440	1440	800	1200
NO. OF LAGS		72	72	60	90
AV. NO. OF DEG. FREEDOM		40.0	40.0	26.7	26.8
MIN. NO. OF DEG. FREEDOM		39.0	36.3	25.0	24.4
MAX. NO. OF DEG. FREEDOM		44.5	42.3	28.8	28.0
DATA FACTOR		0.500	0.050	0.422	0.300
INSTRUMENT DEPTH	FEET	7.25	7.00	11.50	
FREQUENCY RANGE	RADIANS	0-2.513	0-2.513	0-2.094	0-3.142

TABLE IV

SIGNIFICANT WAVE HEIGHTS – MEASURED VERSUS PREDICTED

OWS STATION A MEASURED						GRIDPOINT 20 PREDICTED			
SHIP	DATE	TIME	LOWER LIMIT FT	AVERAGE FT	UPPER LIMIT FT	USWB INPUT FT	USWB INPUT LONG RANGE FT	FNWF INPUT FT	FNWF INPUT LONG RANGE FT
FRANCE II	1967 27 FEB	00	15.8	17.2	18.8	6.2		6.8	
		12	13.0	14.2	15.4	6.2	4.9	8.0	
	4 MAR	00	17.6	19.4	21.2	6.9		7.1	
		12	19.5	21.5	23.7	11.0	8.4	11.7	
	5 MAR	00	20.3	22.4	24.8	7.0		8.5	
		12	17.7	19.6	21.7	6.2	4.0	8.2	
	6 MAR	00	12.7	14.1	15.6	5.9		7.0	
		12	10.6	11.7	13.0	5.5	4.8	6.3	
OWS STATION I						GRIDPOINT 36			
WEATHER ADVISER	1966 4 DEC	12	9.1	9.8	10.6	10.6	9.9		
		18	14.5	15.9	17.5	13.5			
	5 DEC	00	18.4	20.6	23.0	15.7			
		06	21.7	24.2	27.1	24.7	18.2		
		12	28.2	31.6	35.3	31.0	19.9		
		18	32.9	36.4	40.3	33.6			
	6 DEC	00	32.2	35.7	39.6	34.8			
		06	31.6	35.0	38.8	28.1	32.1		
		12	30.2	34.0	38.3	28.8	30.0		
		18	25.7	29.0	32.8	24.2			
OWS STATION J						GRIDPOINT 72			
WEATHER ADVISER	1967 27 FEB	00	11.7	12.7	13.8	12.9		13.4	
		06	12.7	14.1	15.5	13.1	11.0	12.3	10.9
		12	15.8	17.5	19.5	15.3	13.4	16.0	
		18	18.8	20.8	22.9	16.6		19.7	
	28 FEB	00	28.0	31.0	34.4	15.7		20.4	
		06	23.1	25.5	28.2	20.2	15.7	26.4	21.2
		12	17.4	19.5	21.8	18.9	14.0	25.6	

TABLE IV (CONT.)

OWS STATION J						GRIDPOINT 72			
SHIP	DATE	TIME	LOWER LIMIT FT	AVERAGE FT	UPPER LIMIT FT	USWB INPUT FT	USWB INPUT LONG RANGE FT	FNWF INPUT FT	FNWF INPUT LONG RANGE FT
WEATHER ADVISER	1967 4 MAR	00	16.0	17.7	19.7	16.0		22.2	
		06	24.7	27.5	30.6	24.8	13.4	31.3	22.8
		12	20.6	22.9	25.4	23.2	12.5	33.2	
		18	26.1	29.2	32.7	22.4		32.5	
	5 MAR	00	25.7	28.5	31.7	20.8		30.4	
		06	19.1	21.7	24.6	20.6	19.4	25.8	27.2
		12	22.0	24.4	27.0	16.9	16.7	23.6	
		18	27.1	30.3	33.8	15.0		21.3	
	6 MAR	00	28.7	32.3	36.4	13.6		19.1	
		06	20.0	22.1	24.5	17.3	13.1	20.9	16.3
		12	15.4	17.1	18.9	15.2	12.3	16.8	
		18	12.7	14.0	15.4	13.6		13.6	

OWS STATION K — GRIDPOINT 142

SHIP	DATE	TIME	LOWER LIMIT FT	AVERAGE FT	UPPER LIMIT FT	USWB INPUT FT	USWB INPUT LONG RANGE FT	FNWF INPUT FT	FNWF INPUT LONG RANGE FT
FRANCE II	1966 4 DEC	12	8.4	9.2	10.1	9.8	10.4		
	5 DEC	00	7.6	8.3	9.1	10.2			
		12	6.9	7.5	8.3	10.2	9.7		
	6 DEC	00	4.4	4.8	5.3	10.3			
		12	5.9	6.3	6.8	13.2	13.3		
	7 DEC	00	15.0	16.8	18.9	20.2			
WEATHER REPORTER	1967 27 FEB	00	11.0	12.0	13.1	14.6		16.9	
		12	11.6	12.5	13.4	18.0	13.5	15.2	
	4 MAR	00	8.2	9.0	10.0	11.1		8.4	
		06	7.5	8.2	9.0	9.4	11.0	7.4	8.9
		12	6.5	7.1	7.8	11.5	11.3	8.9	
		18	7.9	8.7	9.5	14.3		13.3	
	5 MAR	00	11.8	13.4	15.3	15.3		17.1	
		06	13.6	15.2	16.8	16.4	15.6	17.5	20.2
		12	11.7	13.2	14.8	17.1	15.8	17.1	
		18	14.2	16.2	18.4	16.7		16.9	
	6 MAR	00	14.8	16.5	18.3	15.0		15.8	
		06	13.9	15.6	17.5	14.0	14.1	14.3	14.8
		12	13.8	15.3	17.0	13.9	12.8	14.4	
		18	14.1	15.5	17.1	13.1		13.8	

TABLE IV (CONT.)

ARGUS ISLAND* MEASURED					GRIDPOINT 229 PREDICTED				
DATE	TIME Z	LOWER LIMIT FT	AVERAGE FT	UPPER LIMIT FT	TIME	USWB INPUT LONG RANGE FT	USWB INPUT FT	FNWF INPUT FT	FNWF INPUT LONG RANGE FT
1966									
4 DEC	1500	9.6	10.5	11.5	12	8.2	7.6		
	21Q0	8.3	9.2	10.0	18	10.9			
5 DEC	0900	6.9	7.5	8.1	00	12.4			
	1500	10.7	11.8	13.1	06	12.1	13.0		
6 DEC	0000	9.2	10.1	11.1	12	12.2	12.6		
	0300	6.9	7.4	8.0	18	12.3			
	0600	7.5	8.1	8.8	00	12.3			
	0900	7.2	7.9	8.5	06	10.6	11.5		
	1500	6.8	7.4	8.0	12	9.8	10.7		
	2100	5.7	6.1	6.6	18	8.9			
7 DEC	0600	5.0	5.5	5.9	00	8.3			
1967									
4 MAR	0300	3.6	3.9	4.2	00	6.1		6.3	
	0900	3.7	4.0	4.4	06	6.8	5.8	8.2	5.9
	1500	4.4	4.8	5.4	12	7.4	6.2	10.7	
	2100	4.9	5.4	6.0	18	7.2		6.5	
5 MAR	0600	5.2	5.7	6.3	00	6.8		6.3	
	0900	5.0	5.6	6.2	06	8.5	7.1	7.6	6.0
	1500	4.6	5.1	5.6	12	8.4	7.1	7.3	
	2100	4.3	4.7	5.1	18	7.6		6.7	
6 MAR	0300	3.6	3.9	4.2	00	7.3		6.6	
	0900	3.1	3.4	3.6	06	6.7	6.7	6.2	6.3
	1500	3.7	4.0	4.2	12	6.2	6.1	6.3	
7 MAR	0400	2.6	2.8	3.0	18	6.7		6.3	

*NOTE - OBSERVED AND PREDICTED WAVE HEIGHTS NOT EXACTLY SYNCHRONIZED IN SOME INSTANCES.

TABLE V

SCHEDULE OF FORECAST INTERVALS FOR VARIOUS SYNOPTIC TIMES

Time Z	Forecast Interval Hours
0000	24
0600	6 and 30
1200	12 and 36*
1800	18

*Applies to USWB input only

TABLE VI

SURFACE WINDS – MEASURED VERSUS PREDICTED

OWS STATION A MEASURED					GRIDPOINT 20 PREDICTED			
SHIP	DATE	TIME Z	WIND DIRECTION DEG	WIND SPEED KTS	USWB INPUT DIR SPEED	USWB INPUT LONG RANGE DIR SPEED	FNWF INPUT DIR SPEED	FNWF INPUT LONG RANGE DIR SPEED
FRANCE II	1967 27 FEB	00	50	29	82 – 8		167 – 8	
		12	350	22	356 – 20	36 — 17	48 – 13	
	4 MAR	00	50	47	115 – 12		77 – 10	
		12	10	34	358 – 10	123 — 12	37 – 17	
	5 MAR	00	360	27	352 – 10		8 – 20	
		12	350	18	344 – 6	349 — 5	1 – 9	
	6 MAR	00	30	8	32 – 2		345 – 9	
		12	120	4	349 – 5	5 — 4	1 – 4	
	OWS STATION I				GRIDPOINT 36			
WEATHER ADVISER	1966 4 DEC	12	220	27	284 – 25	299 — 23		
		18	220	33	282 – 29			
	5 DEC	00	270	46	293 – 28			
		06	260	38	48 – 17	307 — 30		
		12	240	40	312 – 45	307 — 32		
		18	260	45	311 – 46			
	6 DEC	00	290	43	319 – 45			
		06	280	48	317 – 38	327 — 41		
		12	280	30	309 – 34	337 — 43		
		18	270	30	297 – 27			
	OWS STATION J				GRIDPOINT 72			
WEATHER ADVISER	1967 27 FEB	00	260	18	293 – 25		297 – 11	
		06	240	34	288 – 29	303 — 24	296 – 26	278 – 11
		12	250	30	311 – 30	312 — 27	319 – 32	
		18	270	43	321 – 31		326 – 35	
	28 FEB	00	280	41	321 – 29		321 – 31	
		06	290	30	325 – 33	323 — 21	324 – 37	317 – 30
		12	260	28	321 – 28	322 — 18	320 – 34	

TABLE VI (CONT.)

OWS STATION J MEASURED					GRIDPOINT 72 PREDICTED			
SHIP	DATE	TIME Z	WIND DIRECTION DEG	WIND SPEED KTS	USWB INPUT DIR SPEED	USWB INPUT LONG RANGE DIR SPEED	FNWF INPUT DIR SPEED	FNWF INPUT LONG RANGE DIR SPEED
WEATHER ADVISER	1967 4 MAR	00	240	48	263 – 23		270 - 32	
		06	230	35	289 – 31	267 — 19	287 - 41	277 — 32
		12	250	28	295 – 29	275 — 18	293 - 37	
		18	240	27	288 – 27		293 - 31	
	5 MAR	00	230	26	269 – 22		292 - 27	
		06	200	14	274 – 22	264 — 18	290 - 29	286 — 23
		12	210	42	263 – 21	238 — 19	274 - 25	
		18	220	55	260 – 20		274 - 25	
	6 MAR	00	260	40	265 – 20		264 - 19	
		06	200	15	285 – 18	283 — 18	282 - 18	264 — 19
		12	110	14	276 – 16	286 — 16	266 - 17	
		18	30	18	265 – 14		287 - 18	
OWS STATION K					GRIDPOINT 142			
FRANCE II	1966 4 DEC	12	CALM	CALM	10 – 4	7 — 9		
	5 DEC	00	120	6	304 – 10			
		12	250	12	250 – 12	250 — 12		
	6 DEC	00	300	16	21 – 6			
		12	270	18	42 – 9	46 — 13		
	7 DEC	00	310	18	352 – 4	—		
WEATHER ADVISER	1967 27 FEB	00	200	20	293 – 20		325 – 16	
		12	230	27	299 – 24	292 — 25	296 – 23	
	4 MAR	00	CALM	CALM	206 – 5		143 - 8	
		06	270	5	329 – 4	341 — 2	12 - 4	148 — 6
		12	260	11	15 – 7	2 — 4	21 - 6	
		18	330	18	13 – 9		30 - 8	
	5 MAR	00	290	10	21 – 8		32 - 8	
		06	260	10	322 – 9	15 — 10	33 - 9	30 — 9
		12	240	15	318 – 9	339 — 6	344 - 9	
		18	210	22	304 – 15		344 - 9	
	6 MAR	00	220	20	286 – 13		296 - 7	
		06	210	23	272 – 12	304 — 11	270 - 11	296 — 7
		12	190	23	273 – 10	270 — 10	272 - 15	
		18	210	27	288 – 16		212 - 14	

TABLE VI (CONT.)

SYNOPTIC SURFACE WINDS - OBSERVED VS. PREDICTED

ARGUS ISLAND OBSERVED				GRIDPOINT 229 PREDICTED				
DATE	TIME Z	WIND DIRECTION DEG	WIND SPEED KTS	TIME Z	USWB INPUT DIR SPEED	USWB INPUT LONG RANGE DIR SPEED	FNWF INPUT DIR SPEED	FNWF INPUT LONG RANGE DIR SPEED
1966								
4 DEC	12	325	27	12	38 – 17	48 —— 12		
	15	330	22	18	46 – 21			
	18	350	26					
	21	15	13					
5 DEC	12	340	18	00	48 – 25			
	15	20	16	06	51 – 18	38 —— 22		
	18	360	20	12	45 – 20	56 —— 19		
	21	15	19	18	62 – 13			
6 DEC	12	355	13	12	29 – 11	85 —— 11		
	15	15	17	18	49 – 7			
	18	5	18					
	21	5	17	00	81 – 8			
1967								
4 MAR	00	200	8	00	301 – 10		271 – 10	
	06	265	7	06	304 – 13	287 —— 10	286 – 13	280 —— 11
	12	350	4	12	307 – 12	266 —— 10	290 – 12	
	15	20	3	18	303 – 10		290 – 10	
	18	120	4					
	21	185	1					
5 MAR	00	CALM	CALM	00	322 – 6		278 – 8	
	06	305	5	06	3 – 4	274 —— 6	319 – 6	279 —— 7
	12	275	3	12	228 – 3	277 —— 8	331 – 3	
	15	240	4	18	231 – 2		331 – 3	
	18	240	6					
	21	250	4					
6 MAR	00	220	3	00	241 – 7		271 – 5	
	06	210	9	06	248 – 7	258 —— 10	274 – 12	271 —— 5
	12	230	10	12	252 – 10	266 —— 12	283 – 13	
	15	220	10	18	291 – 8		286 – 11	
	18	205	11					
	21	195	11					

TABLE VII

STATISTICAL ANALYSIS SUMMARY – USWB INPUT

WAVE HEIGHTS – WIND DIRECTIONS – WIND SPEEDS								
			BIAS			R. M. S. ERROR		
OWS STATION	FOR TIME ENDING IN	# OBS	WAVE HEIGHT IN FEET	WIND DIR. IN DEG	WIND SPEED IN KNOTS	WAVE HEIGHT FEET	WIND DIR. DEGREES	WIND SPEED KNOTS
A	12 HRS.	4	-9.5	-36	-9	±9.9	±65.9	±13.5
	24 HRS.	4	-11.8	+23	-20	±12.1	±36.4	±22.3
	36 HRS.	4	-11.2	+11	-10	±11.7	±83.8	±13.0
	ALL	12	-10.8	-1	-13	±11.3	±65.1	±16.8
I	6 HRS.	2	-3.2	+93	-16	±4.9	±107.8	±16.5
	12 HRS.	3	-1.7	+55	+2	±3.0	±58.1	±3.9
	18 HRS.	3	-3.3	+47	-2	±3.5	±48.9	±3.0
	24 HRS.	2	-2.9	+26	-8	±3.5	±26.2	±12.8
	30 HRS.	2	-4.5	+47	-8	±4.7	±47.0	±7.6
	36 HRS.	3	-5.2	+68	+0	±7.1	±68.3	±9.1
	ALL	15	-3.4	+56	-4	±4.7	±63.4	±9.3
J	6 HRS.	5	-3.0	+60	+1	±3.5	±62.8	±5.0
	12 HRS.	5	-2.4	+77	-4	±3.6	±89.2	±9.4
	18 HRS.	4	-6.7	+ 4	-13	±8.6	±74.4	±18.6
	24 HRS.	5	-8.6	+28	-11	±11.4	±31.1	±15.7
	30 HRS.	5	-7.7	+56	-6	±8.8	±59.0	±9.6
	36 HRS.	5	-6.5	+71	-9	±6.9	±89.5	±12.2
	ALL	29	-5.8	+51	-7	±7.7	±70.5	±12.3
K	6 HRS.	3	+0.3	+61	-4	±1.3	±61.0	±6.4
	12 HRS.	7	+3.2	+108	-5	±4.2	±112.3	±7.1
	18 HRS.	3	+1.2	+72	-9	±3.5	±74.8	±9.1
	24 HRS.	7	+2.3	+33	-3	±3.0	±100.5	±7.5
	30 HRS.	3	+0.6	+93	-5	±1.8	±95.0	±7.1
	36 HRS.	7	+2.2	+89	-4	±3.5	±93.0	±6.9
	ALL	30	+2.0	+76	-5	±3.3	±95.1	±7.3
ALL	OWS STATION	86	-3.4	+53	-6	±6.7	±77.6	±11.1
ARGUS ISLAND	6 HRS.	7	+3.1	+45	+1	±3.2	±45.9	±3.7
	12 HRS.	6	+1.4	+17	-1	±2.4	±50.4	±5.4
	18 HRS.	6	+2.1	+16	-4	±2.2	±89.7	±7.1
	24 HRS.	6	+2.4	+61	+4	±2.5	±72.9	±4.4
	30 HRS.	7	+3.1	+13	+2	±3.3	±35.4	±2.0
	36 HRS.	6	+1.1	+34	-1	±2.3	±69.7	±7.0
	ALL	38	+2.3	+27	-1	±2.7	±66.1	±5.4
ALL OBS	6 HRS.	17	+0.1	+62	-3	±3.3	±68.2	±8.0
	12 HRS.	25	-1.0	+48	-3	±5.1	±81.4	±8.4
	18 HRS.	16	-0.7	+29	-7	±5.0	±76.8	±11.0
	24 HRS.	24	-2.7	+32	-8	±8.9	±66.0	±13.8
	30 HRS.	17	-1.4	+53	-4	±5.5	±63.7	±7.5
	36 HRS.	25	-2.8	+56	-5	±6.5	±82.5	±9.6
	ALL	124	-1.6	+46	-5	±6.2	±75.0	±10.1

TABLE VIII

STATISTICAL ANALYSIS SUMMARY - FNWF INPUT

WAVE HEIGHTS - WIND DIRECTIONS - WIND SPEEDS								
			BIAS			R. M. S. ERROR		
OWS STATION	FOR TIME ENDING IN	# OBS.	WAVE HEIGHT IN FEET	WIND DIR. IN DEG	WIND SPEED IN KNOTS	WAVE HEIGHT FEET	WIND DIR. DEGREES	WIND SPEED KNOTS
A	12 HRS	4	-8.2	-6	-9	±8.6	±67.8	±10.6
	24 HRS	4	-10.9	+27	-16	±11.2	±64.2	±21.6
	ALL	8	-9.6	+11	-12	±10.0	±66.0	±17.0
J	6 HRS	5	+1.2	+64	+5	±2.7	±66.9	±8.8
	12 HRS	5	+2.8	+78	+1	±5.4	±87.9	±9.2
	18 HRS	4	-1.8	+15	-9	±4.8	±69.8	±15.7
	24 HRS	5	-3.1	+35	-11	±7.6	±39.5	±13.0
	30 HRS	5	-2.5	+52	-3	±4.8	±56.4	±11.3
	ALL	24	-0.7	+50	-3	±5.3	±65.9	±11.7
K	6 HRS	3	+0.1	+98	-5	±1.6	±102.7	±7.0
	12 HRS	4	+1.9	+93	-6	±2.6	±95.6	±5.9
	18 HRS	3	+1.2	+65	-12	±2.9	±84.8	±12.1
	24 HRS	4	+1.8	+101	-3	±9.9	±103.0	±7.9
	30 HRS	3	+1.6	+31	-5	±3.0	±114.2	±9.3
	ALL	17	+1.4	+79	-6	±2.7	±100.3	±8.5
ALL OWS STATIONS		49	-1.4	+53	-6	±5.7	±79.0	±11.9
ARGUS ISLAND	6 HRS	4	+3.2	+33	+3	±3.3	±39.7	±3.9
	12 HRS	3	+3.5	+16	+4	±3.9	±56.4	±4.9
	18 HRS	3	+1.8	+126	-1	±1.9	±131.0	±5.7
	24 HRS	3	+2.0	+61	+4	±2.1	±61.8	±4.9
	30 HRS	4	+2.2	+17	+1	±2.5	±39.2	±3.5
	ALL	17	+2.5	+50	+2	±2.9	±74.6	±4.7
ALL OBS.	6 HRS	12	+1.6	+65	+2	±2.7	±73.1	±7.2
	12 HRS	16	-0.1	+49	-3	±5.7	±80.3	±8.2
	18 HRS	10	+0.2	+63	-7	±3.6	±96.1	±12.3
	24 HRS	16	-2.9	+50	-7	±7.3	±67.5	±13.8
	30 HRS	12	+0.1	+37	-2	±3.7	±73.7	±9.2
	ALL	66	+0.4	±52	-4	±5.1	±78.0	±10.5

TABLE IX

STATISTICAL ANALYSIS COMPARISONS

WAVE HEIGHTS - WIND DIRECTIONS - WIND SPEEDS								
			BIAS			R. M. S. ERROR		
OWS STATION	INPUT	NO. OF OBS	WAVE HEIGHT FT	WIND DIRECTION DEG	WIND SPEED KTS	WAVE HEIGHT FT	WIND DIRECTION DEG	WIND SPEED KTS
A	USWB	12	-10.8	-1	-13	±11.3	±65.1	±16.8
	FNWF	8	-9.6	+11	-12	±10.0	±66.0	±17.0
J	USWB	29	-5.8	+51	-7	±7.7	±70.5	±12.3
	FNWF	24	-0.7	+50	-3	±5.3	±65.9	±11.7
K	USWB	30	+2.0	+76	-5	±3.3	±95.1	±7.3
	FNWF	17	+1.4	+79	-6	±2.7	±100.3	±8.5
ALL SHIPS	USWB	86	-3.4	+53	-6	±6.7	±77.6	±11.1
	FNWF	49	-1.4	+53	-6	±5.7	±79.0	±11.9
ARGUS ISLAND	USWB	38	+2.3	+27	-1	±2.7	±66.1	±5.4
	FNWF	17	+2.5	+50	+2	±2.9	±74.6	±4.7
ALL OBS	USWB	124	-1.6	+46	-5	±6.2	±75.0	±10.1
	FNWF	66	+0.4	+52	-4	±5.1	±78.0	±10.5
COMBINED	OBS	190	-1.2	+49	-5	±5.8	±76.1	±10.3

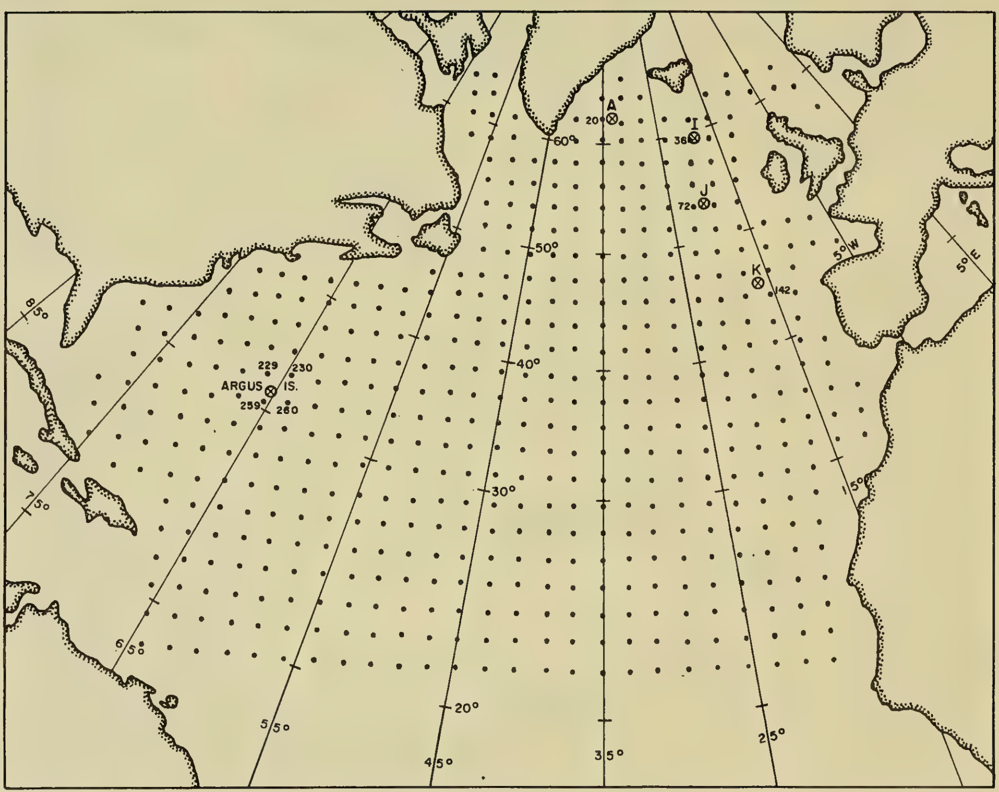

FIGURE 1. MAP OF NORTH ATLANTIC GRIDPOINTS, OWS STATIONS AND ARGUS ISLAND.

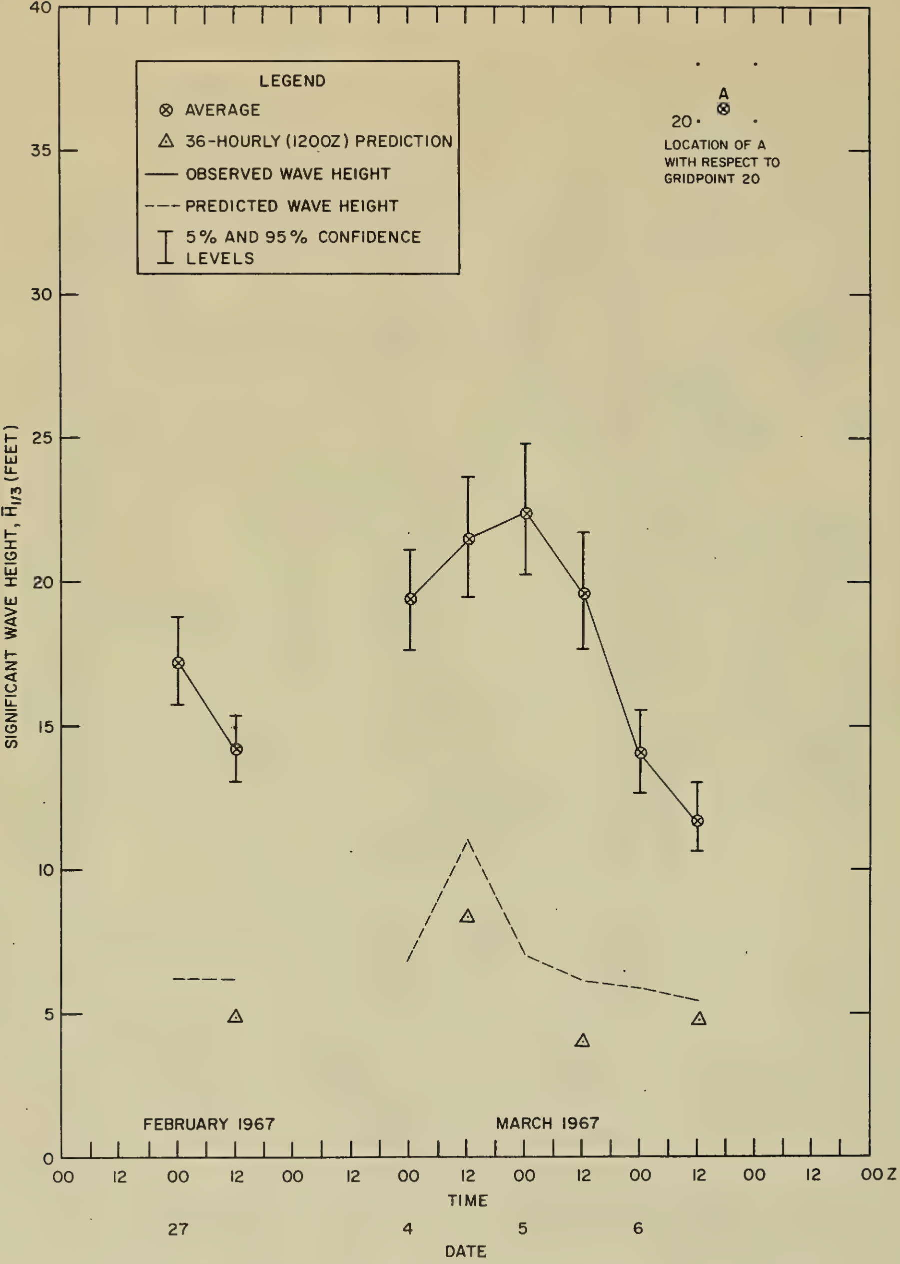

FIGURE 2. COMPARISON OF OBSERVED (MEASURED) AND PREDICTED WAVE HEIGHTS AT STATION A (USWB WIND INPUT)

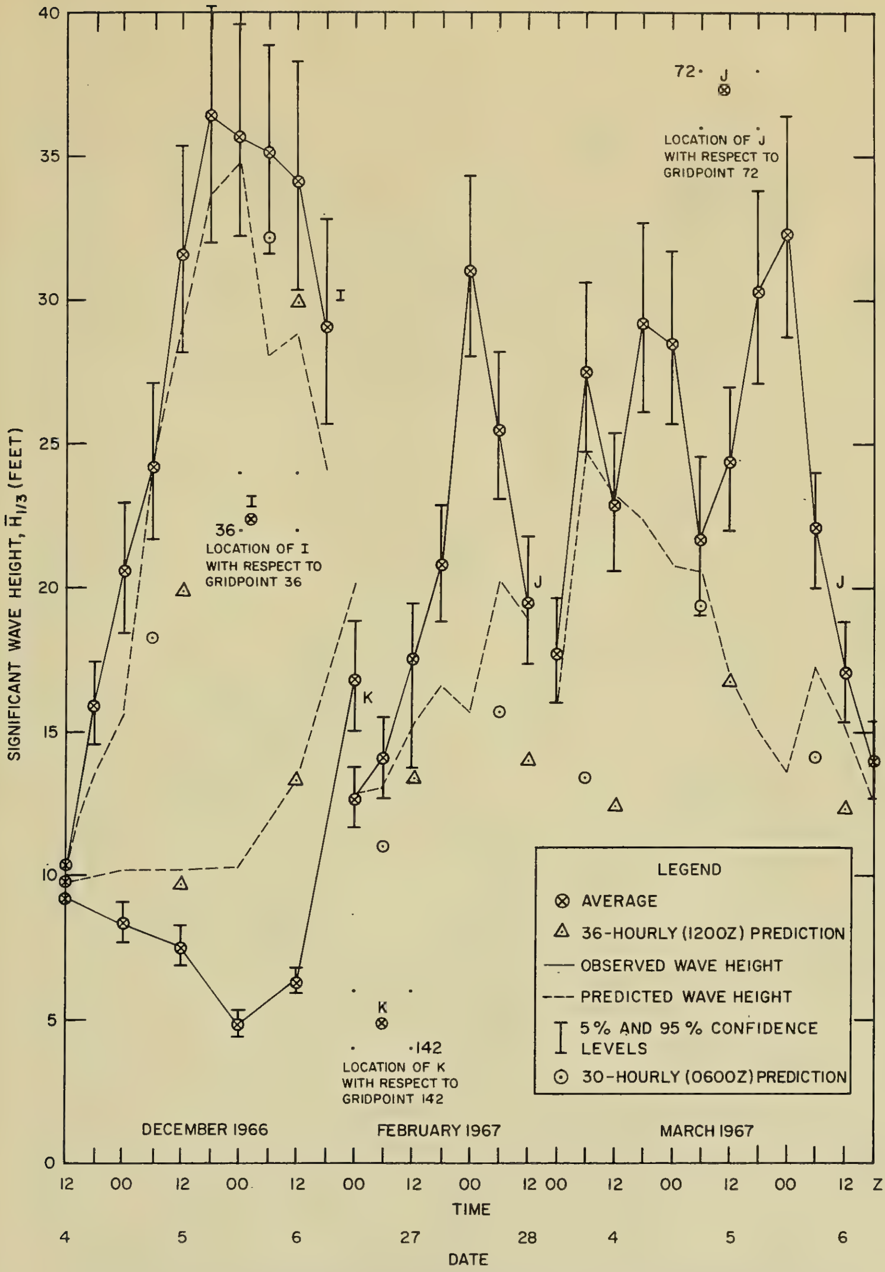

FIGURE 3. COMPARISON OF OBSERVED (MEASURED) AND PREDICTED WAVE HEIGHTS AT STATIONS I, J, K (USWB WIND INPUT).

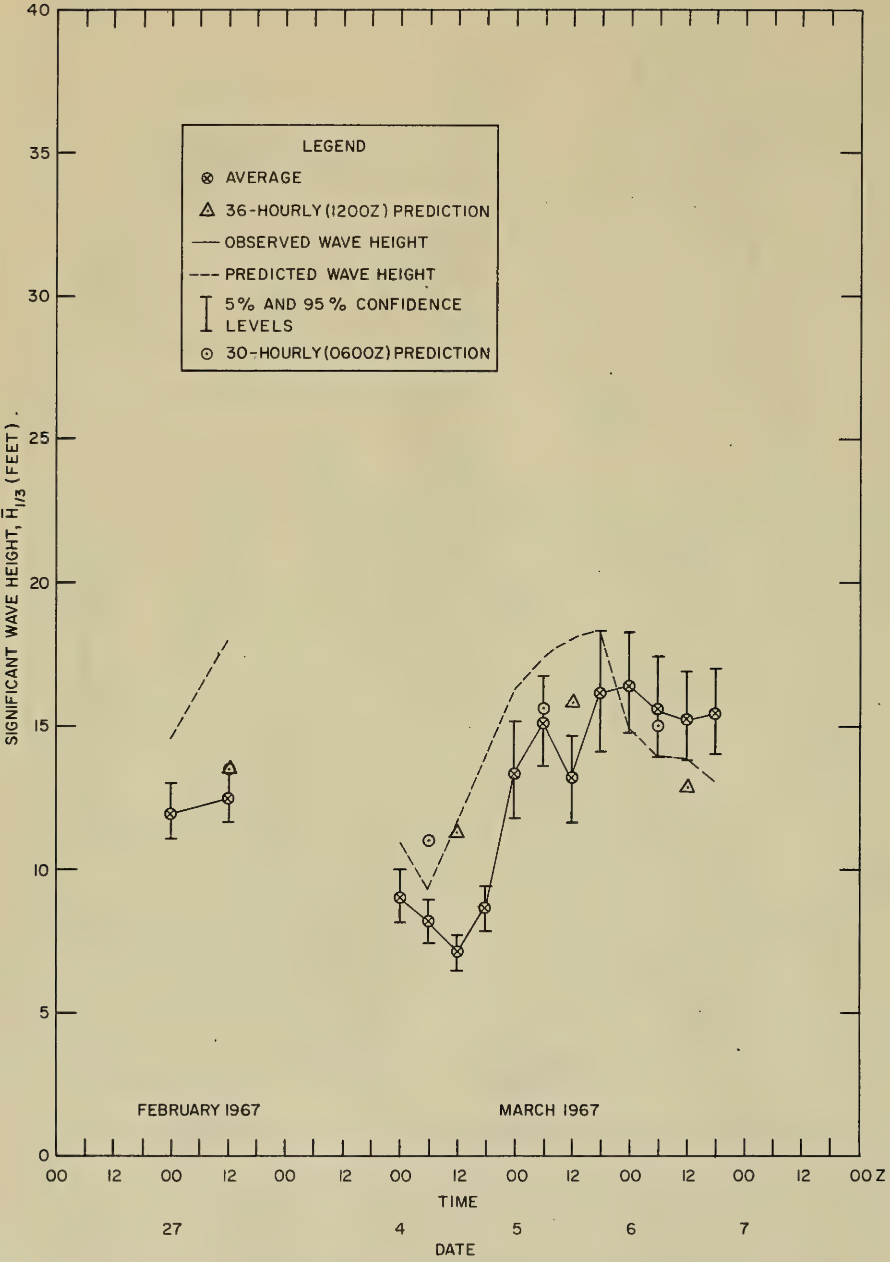

FIGURE 4. COMPARISON OF OBSERVED (MEASURED) AND PREDICTED WAVE HEIGHTS AT STATION K (USWB WIND INPUT).

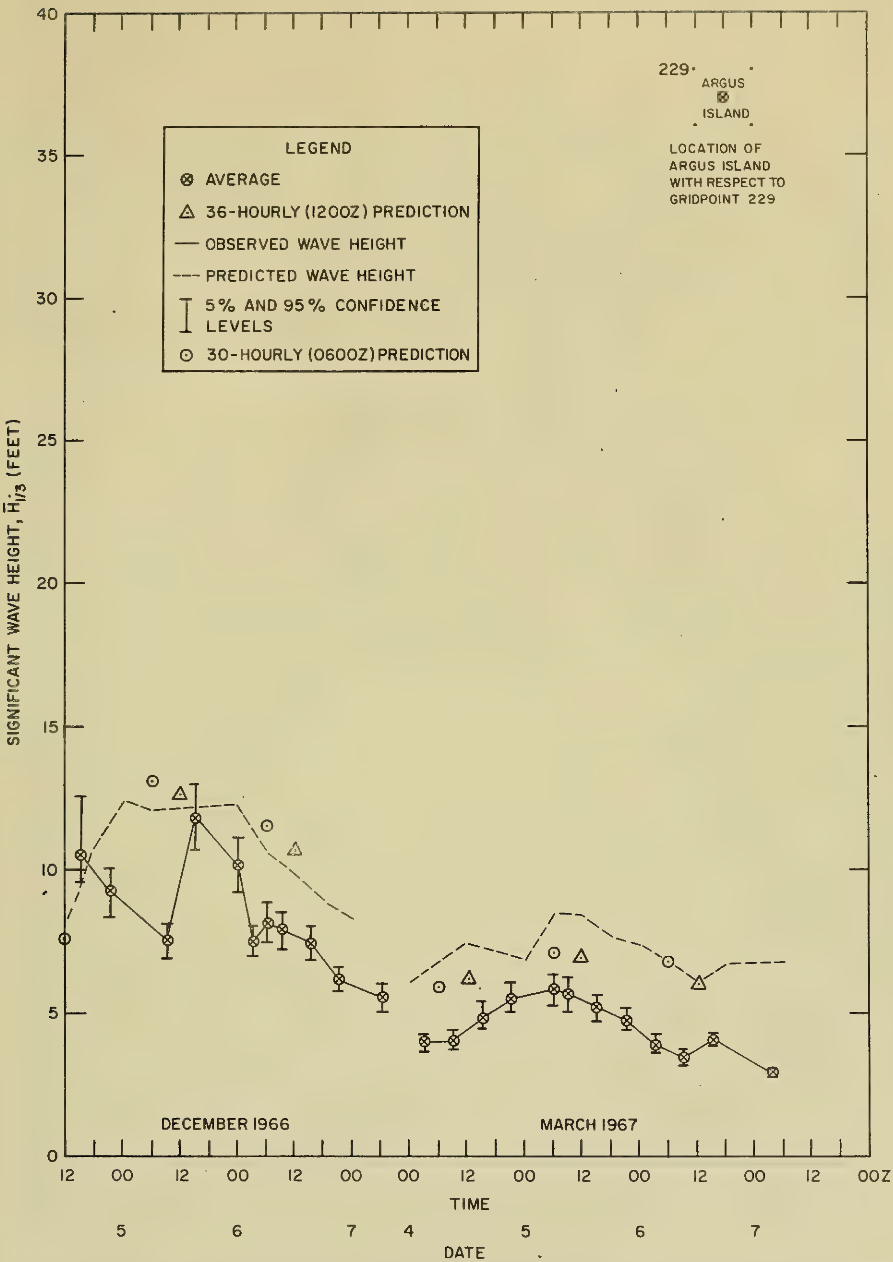

FIGURE 5. COMPARISON OF OBSERVED (MEASURED) AND PREDICTED WAVE HEIGHTS AT ARGUS ISLAND (USWB WIND INPUT).

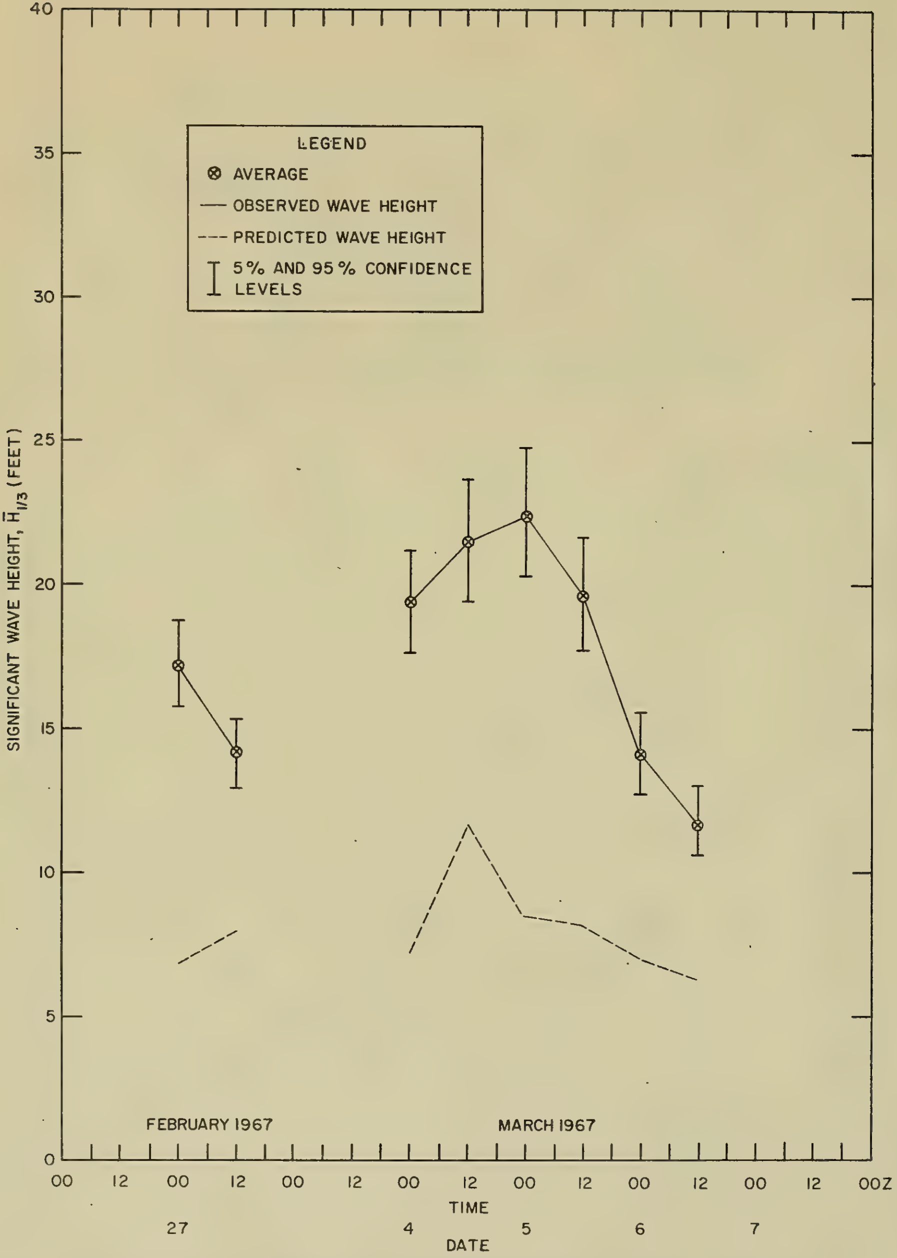

FIGURE 6. COMPARISON OF OBSERVED (MEASURED) AND PREDICTED WAVE HEIGHTS AT STATION A (FNWF WIND INPUT).

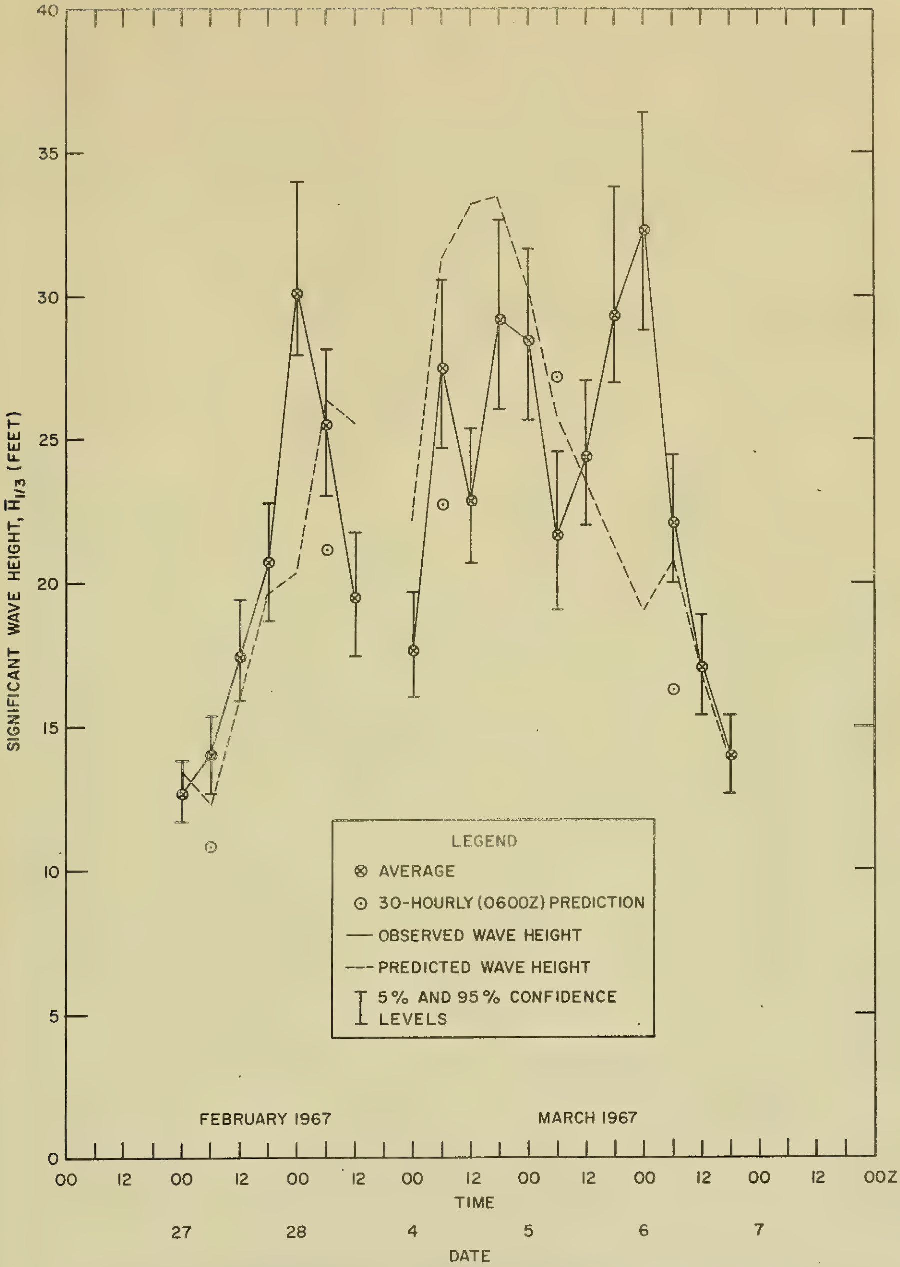

FIGURE 7. COMPARISON OF OBSERVED (MEASURED) AND PREDICTED WAVE HEIGHTS AT STATION J (FNWF WIND INPUT).

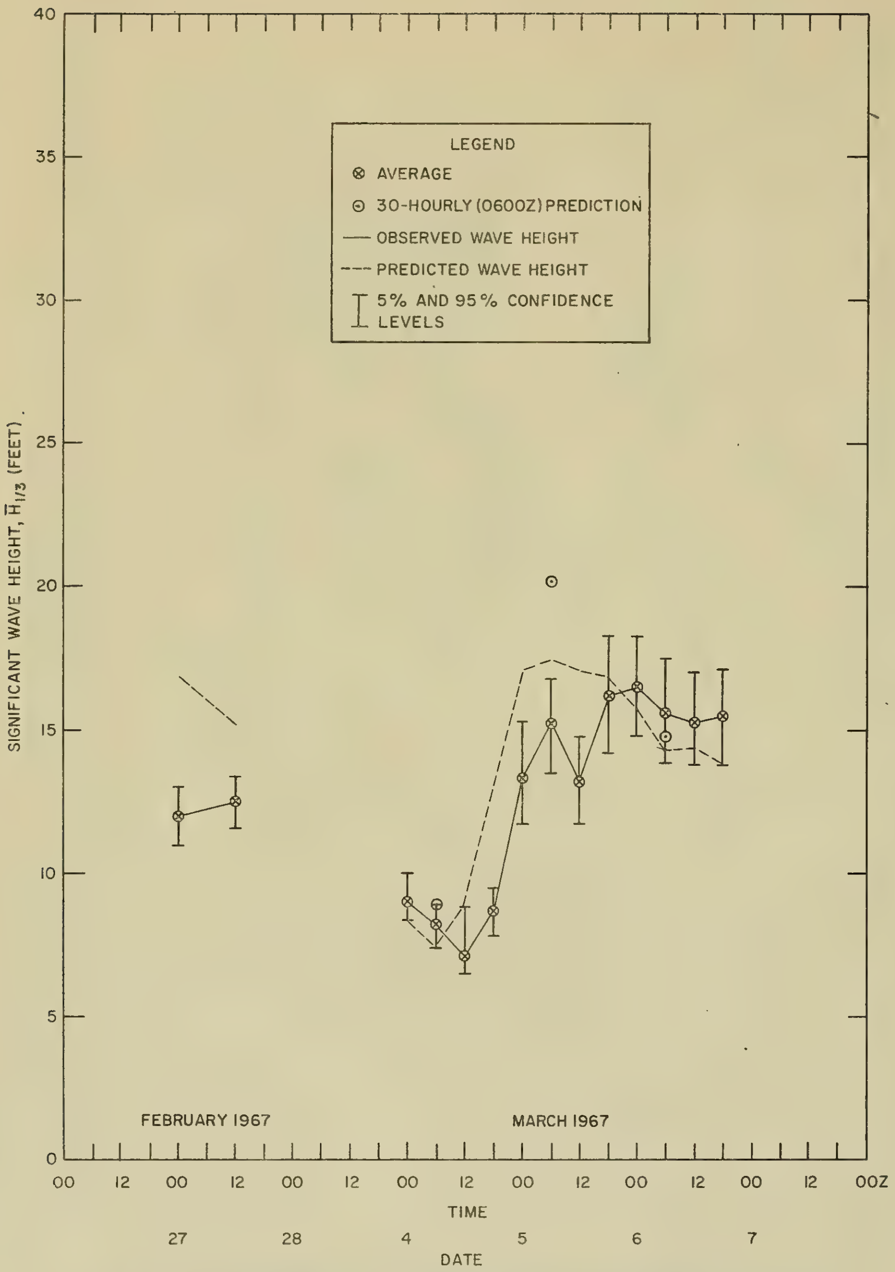

FIGURE 8. COMPARISON OF OBSERVED (MEASURED) AND PREDICTED WAVE HEIGHTS AT STATION K (FNWF WIND INPUT).

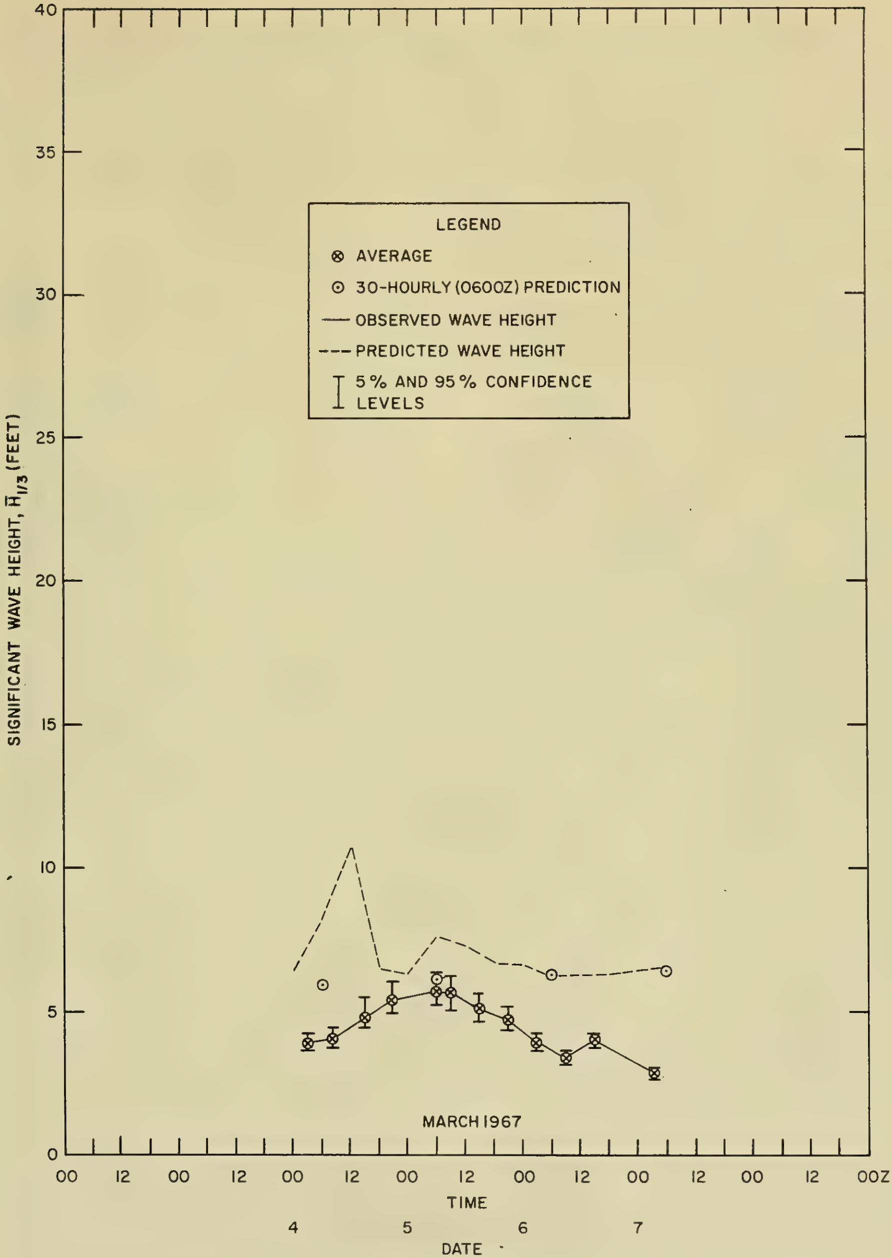

FIGURE 9. COMPARISON OF OBSERVED (MEASURED) AND PREDICTED WAVE HEIGHTS AT ARGUS ISLAND (FNWF WIND INPUT).

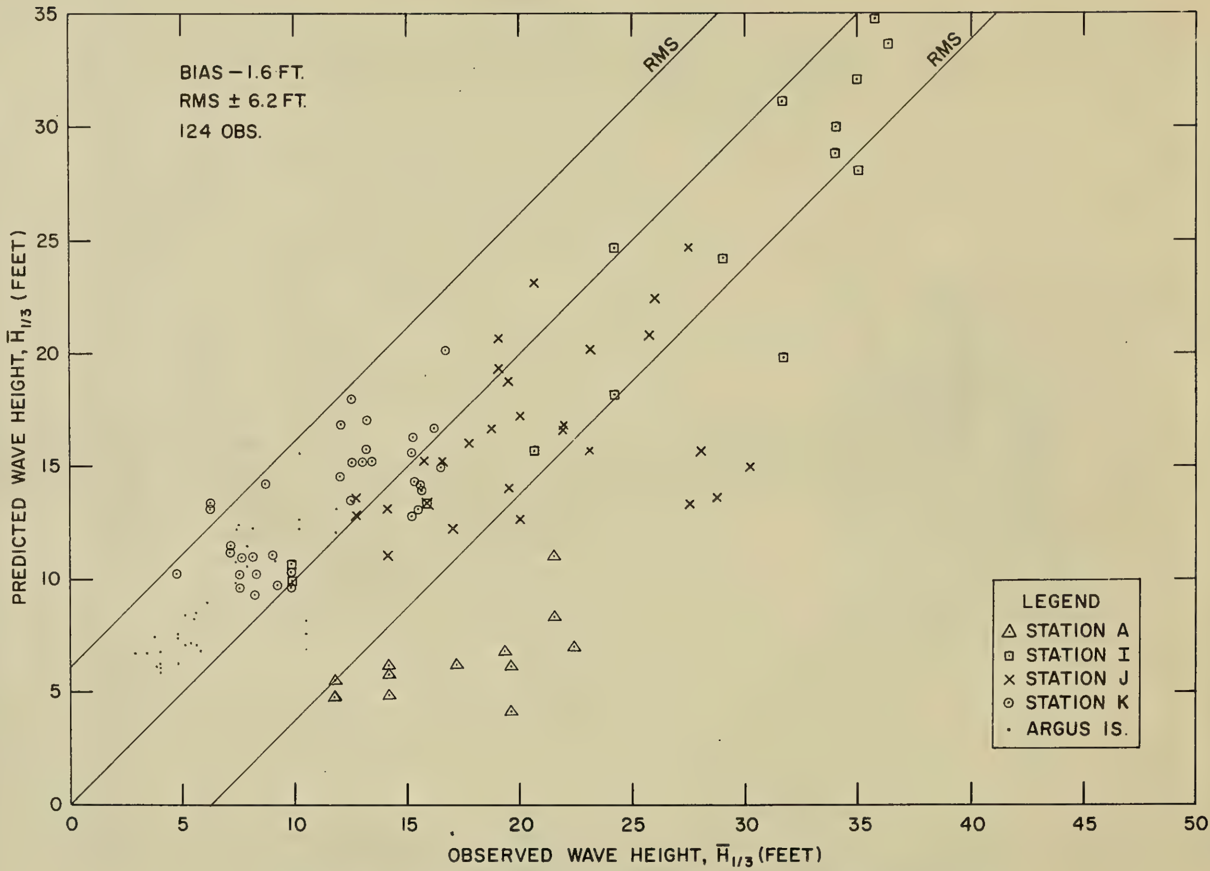

FIGURE 10. SCATTER DIAGRAM FOR WAVE HEIGHTS (USWB INPUT).

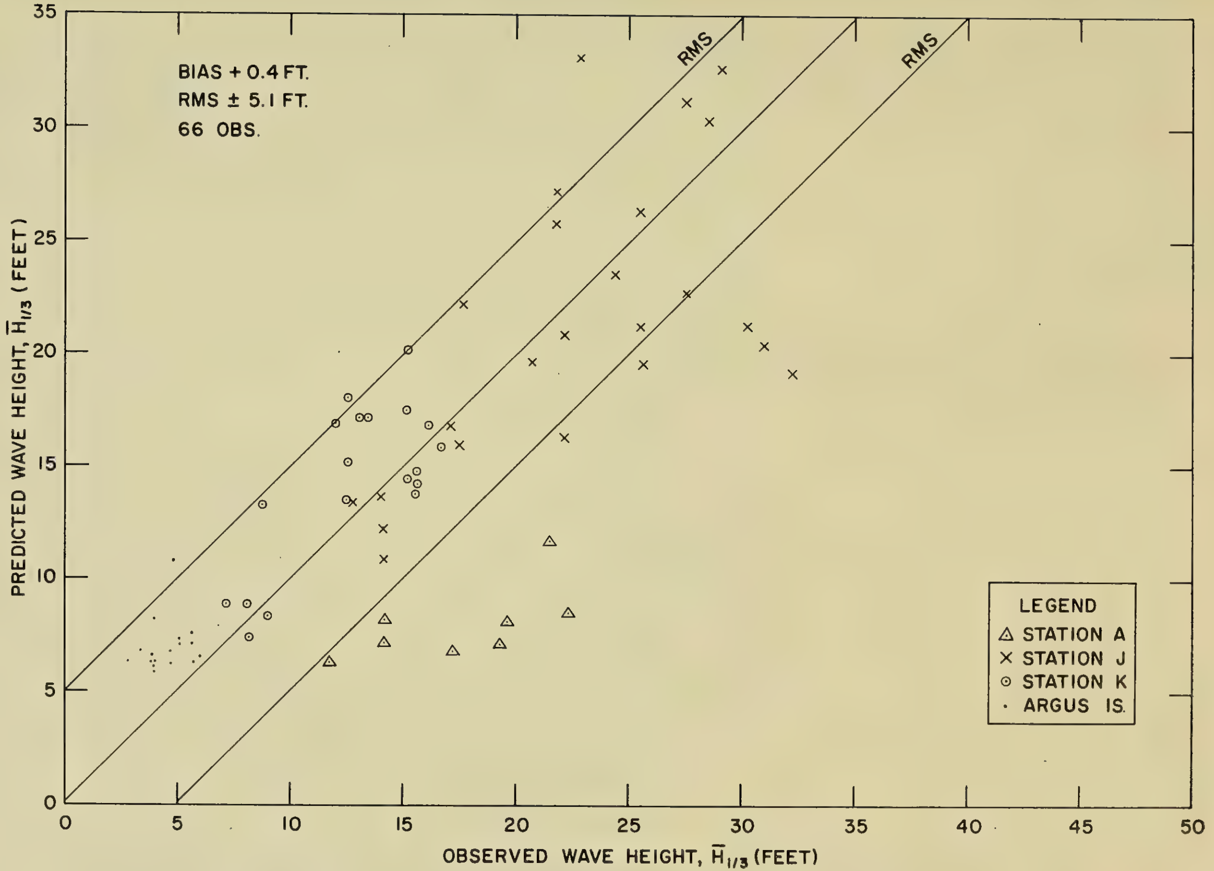

FIGURE 11. SCATTER DIAGRAM FOR WAVE HEIGHTS (FNWF INPUT).

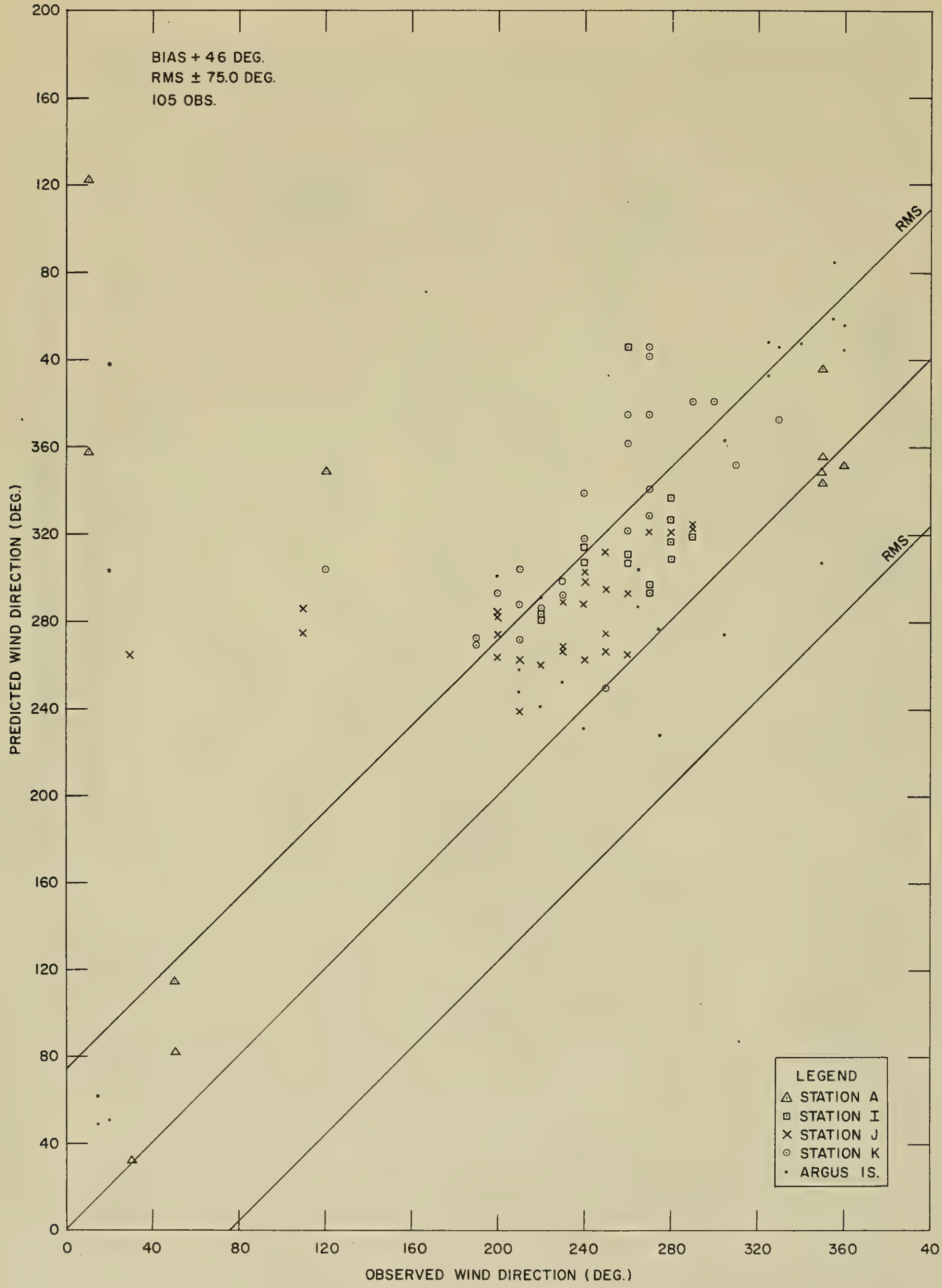

FIGURE 12. SCATTER DIAGRAM FOR WIND DIRECTIONS (USWB INPUT).

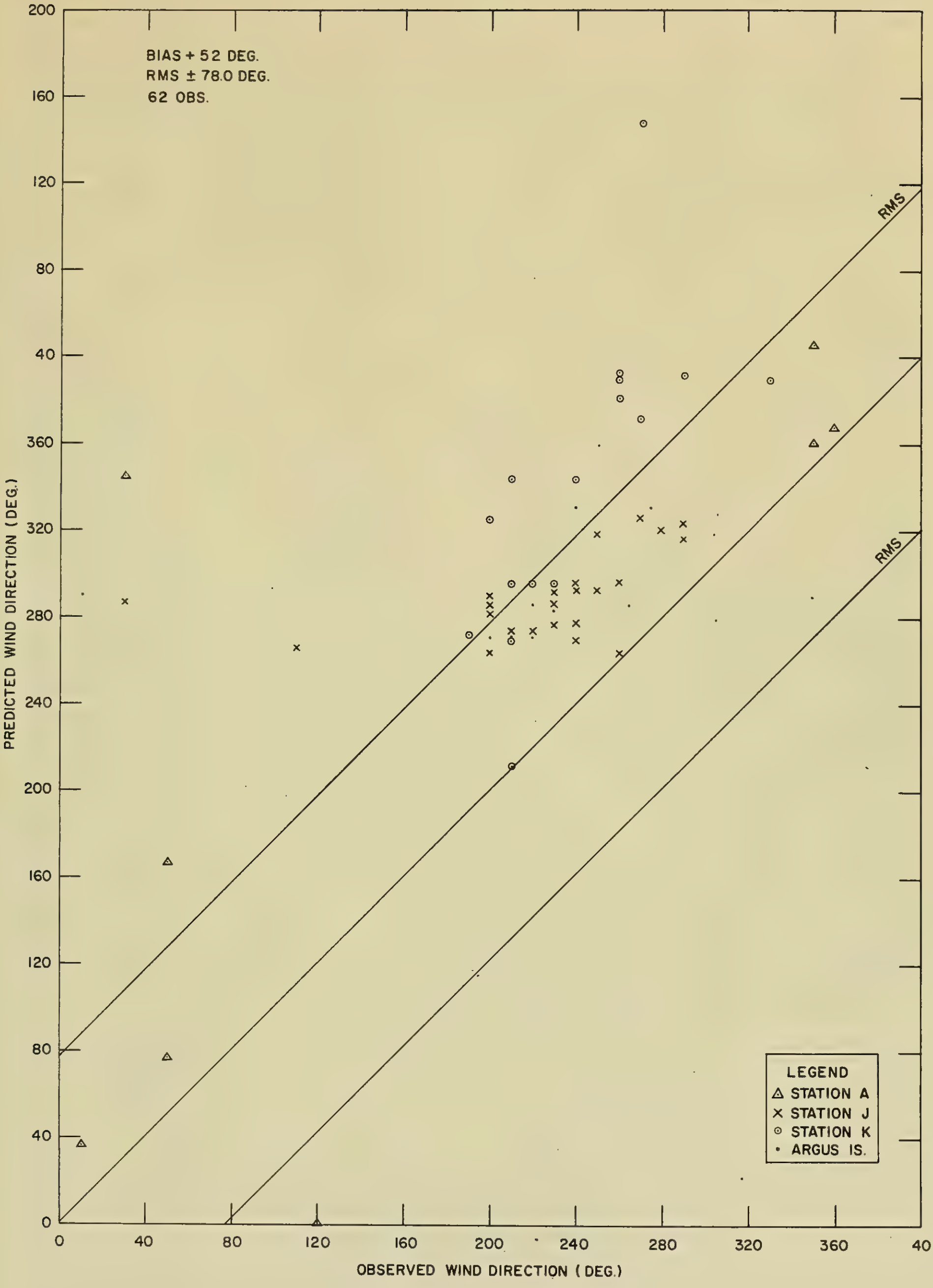

FIGURE 13. SCATTER DIAGRAM FOR WIND DIRECTIONS (FNWF INPUT).

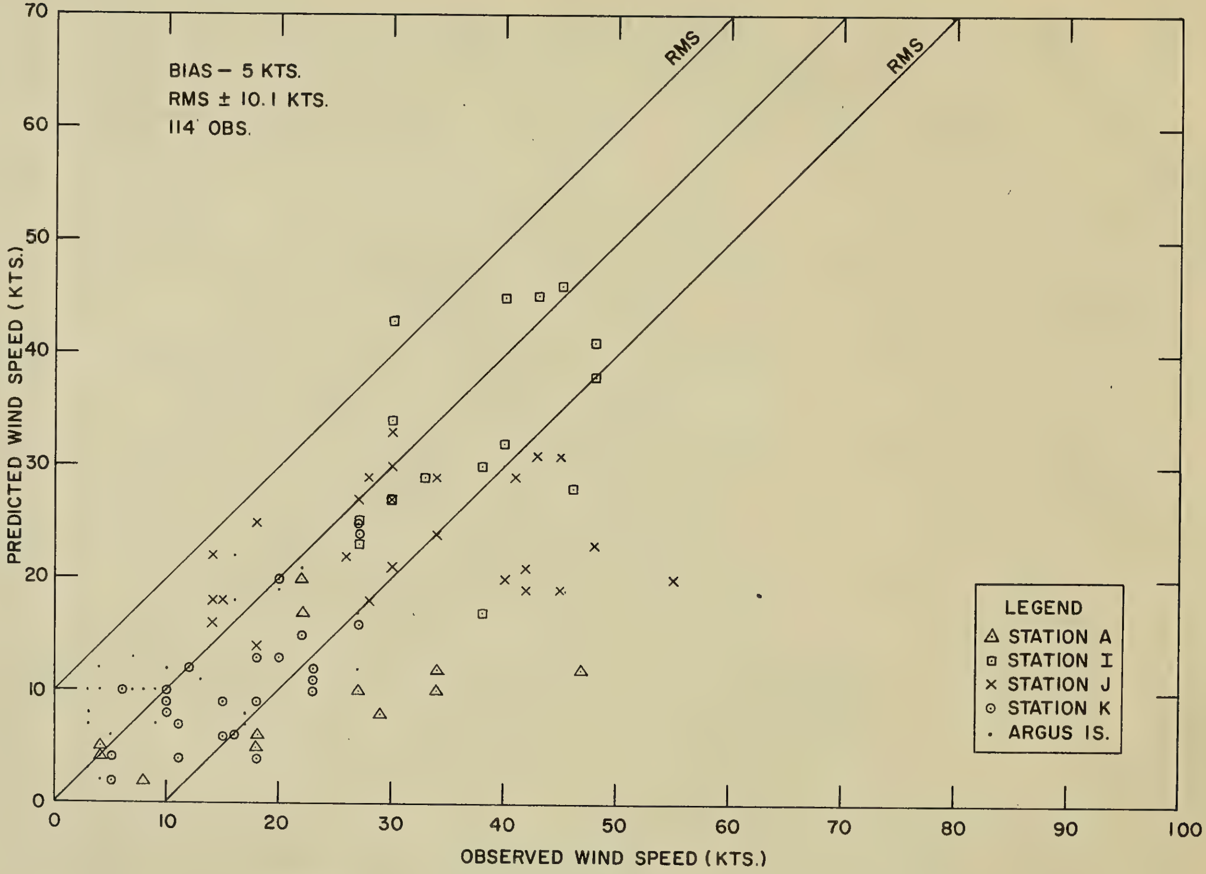

FIGURE 14. SCATTER DIAGRAM FOR WIND SPEEDS (USWB INPUT).

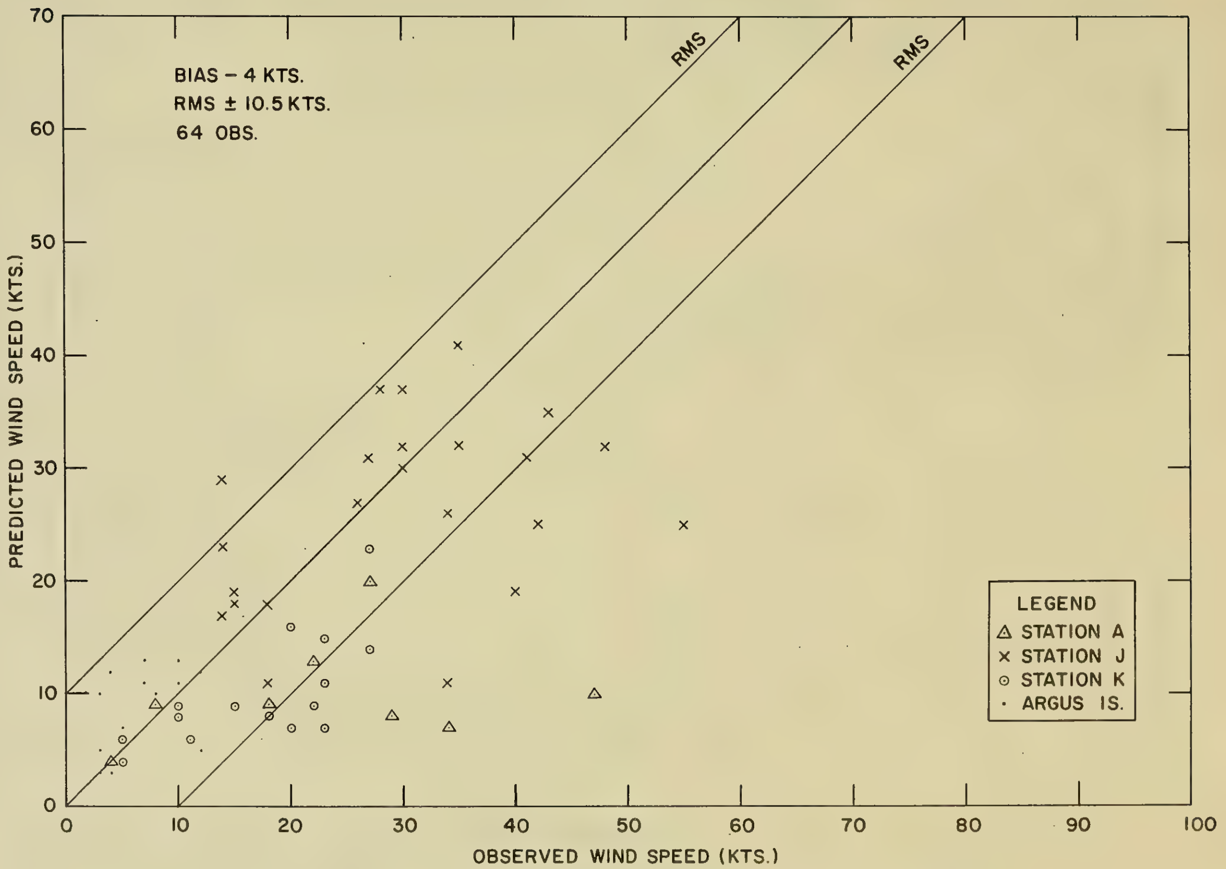

FIGURE 15. SCATTER DIAGRAM FOR WIND SPEEDS (FNWF INPUT).

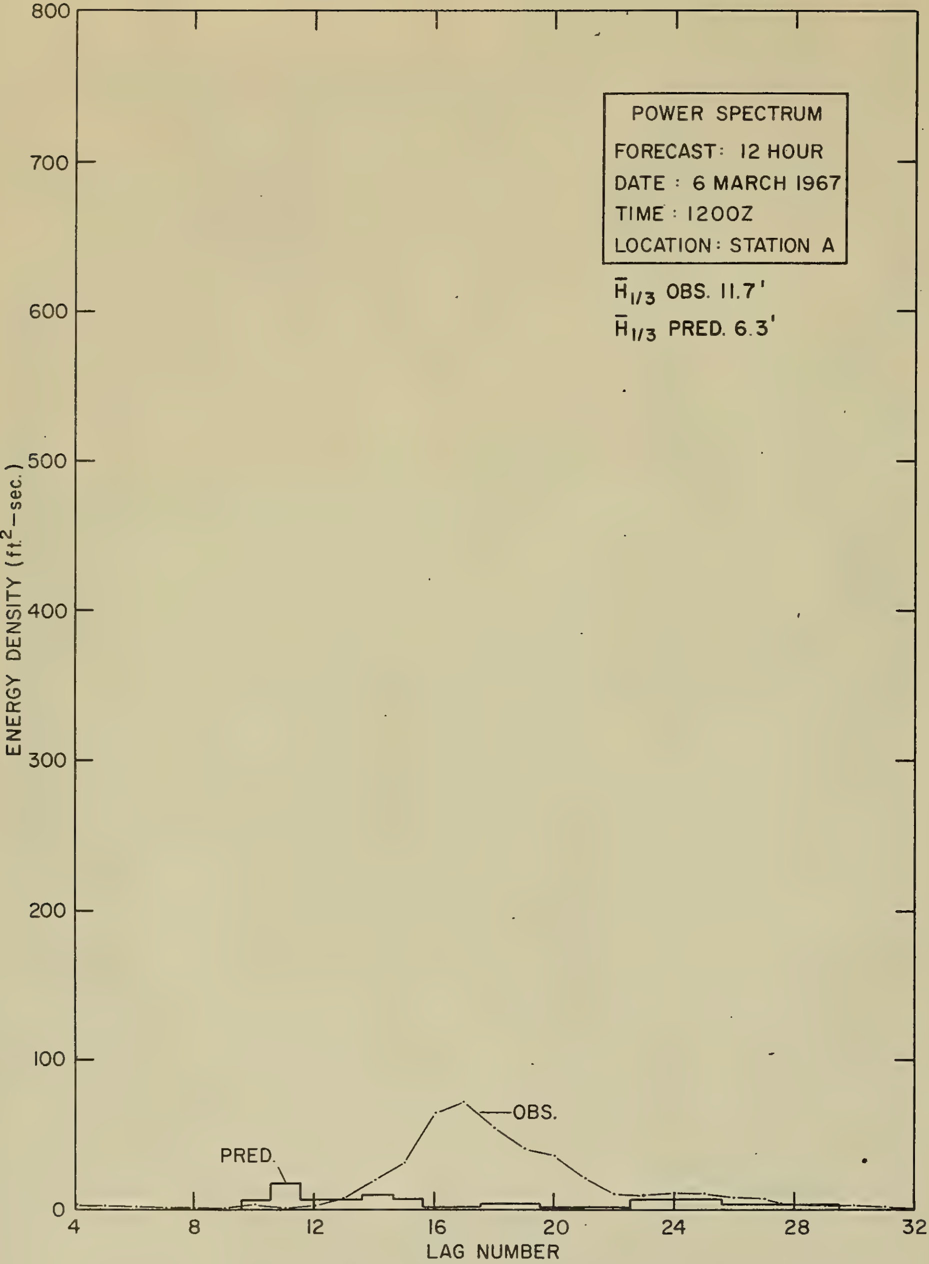

FIGURE 16. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED– GREATEST CORRELATION (FNWF INPUT).

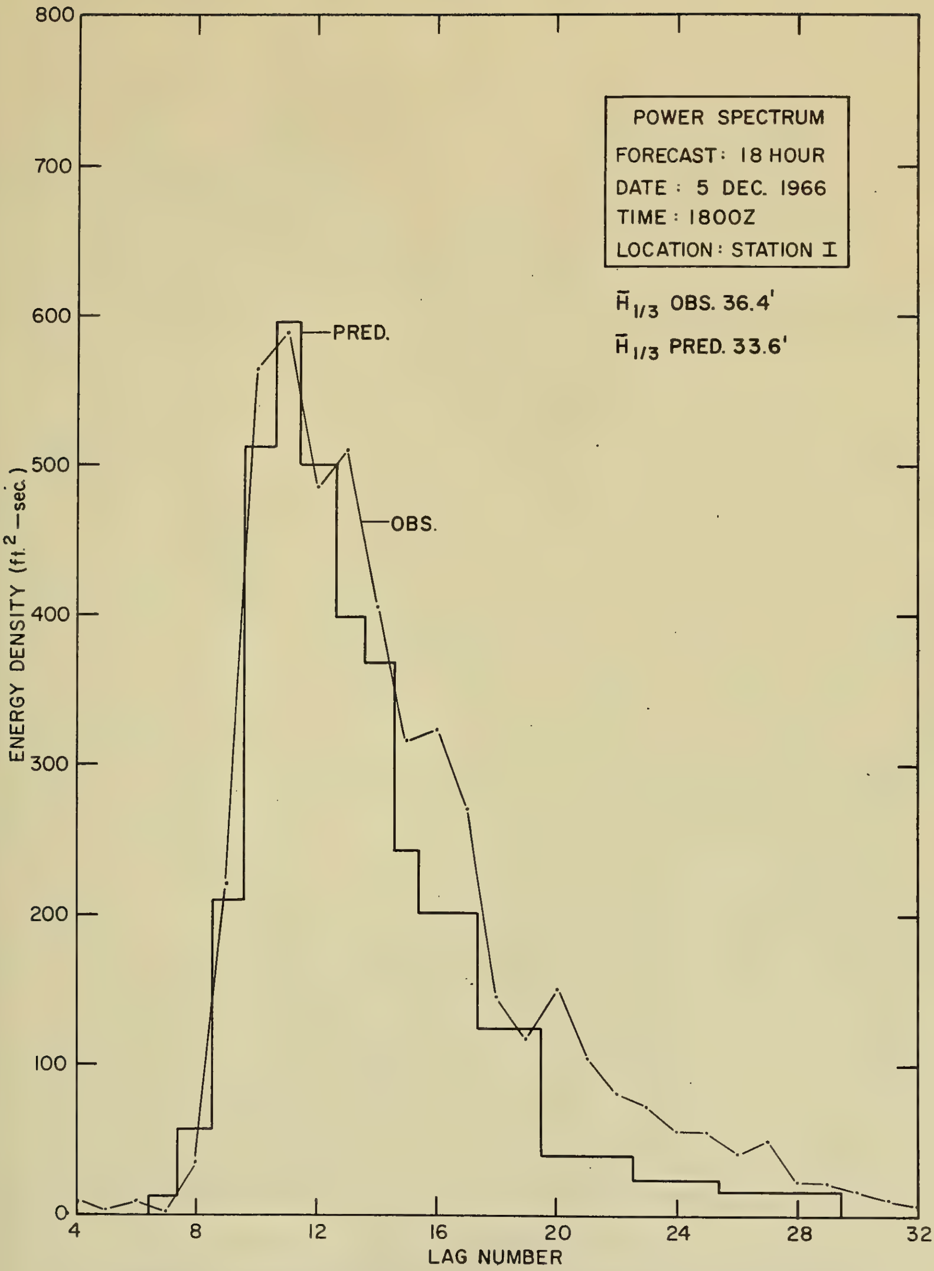

FIGURE 17. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - GREATEST CORRELATION (USWB INPUT).

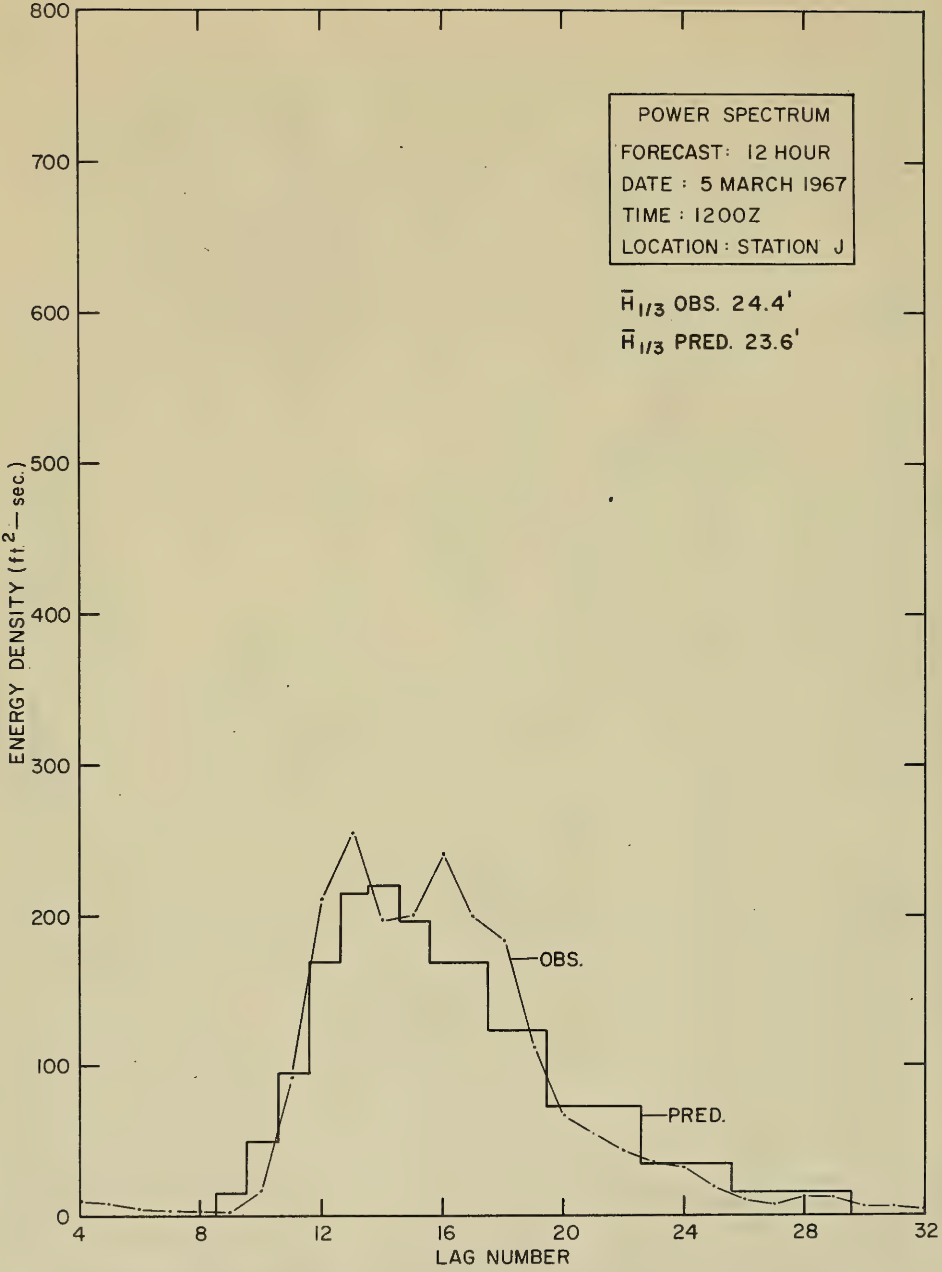

FIGURE 18. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - GREATEST CORRELATION (FNWF INPUT).

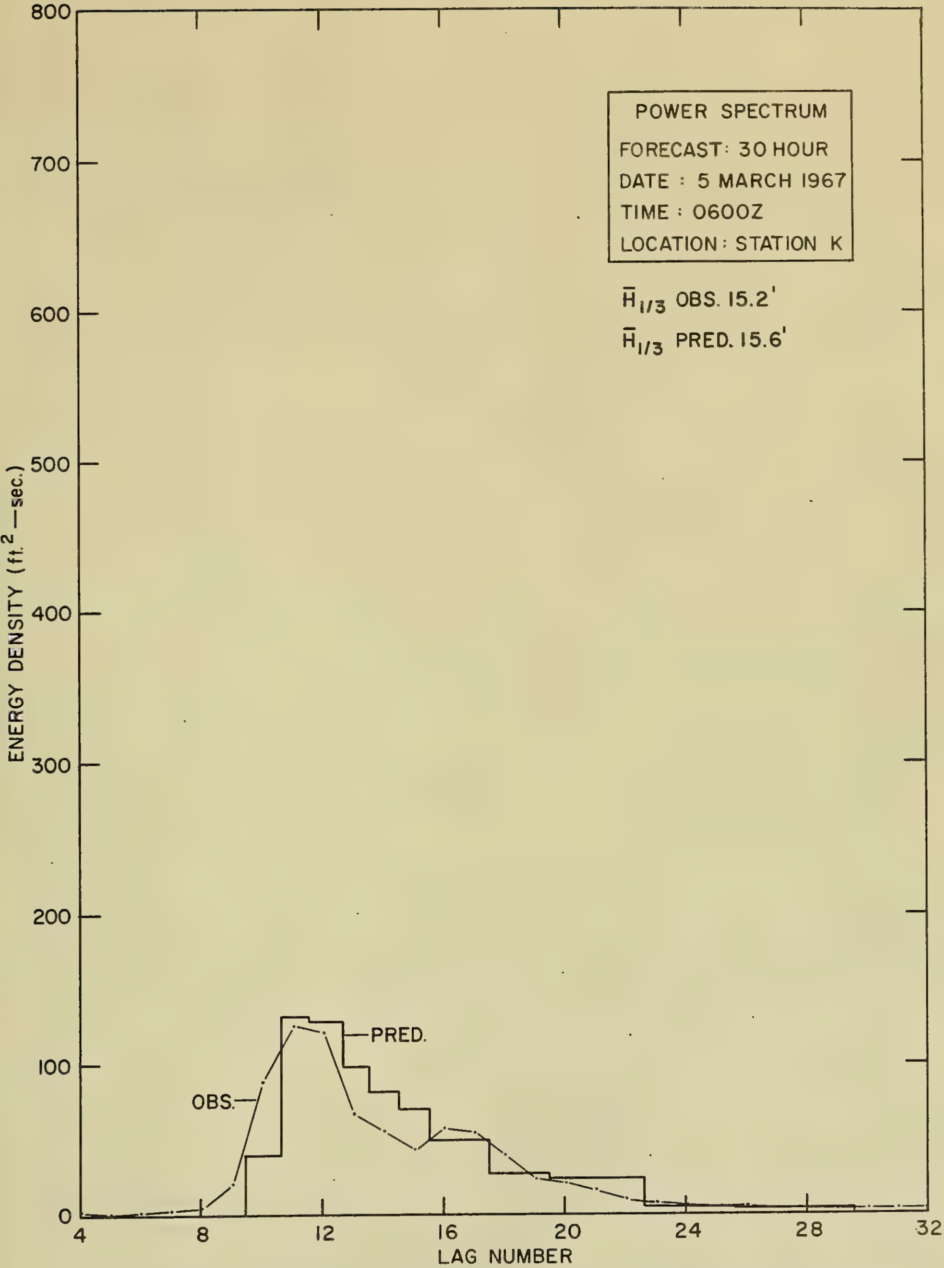

FIGURE 19. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - GREATEST CORRELATION (USWB INPUT).

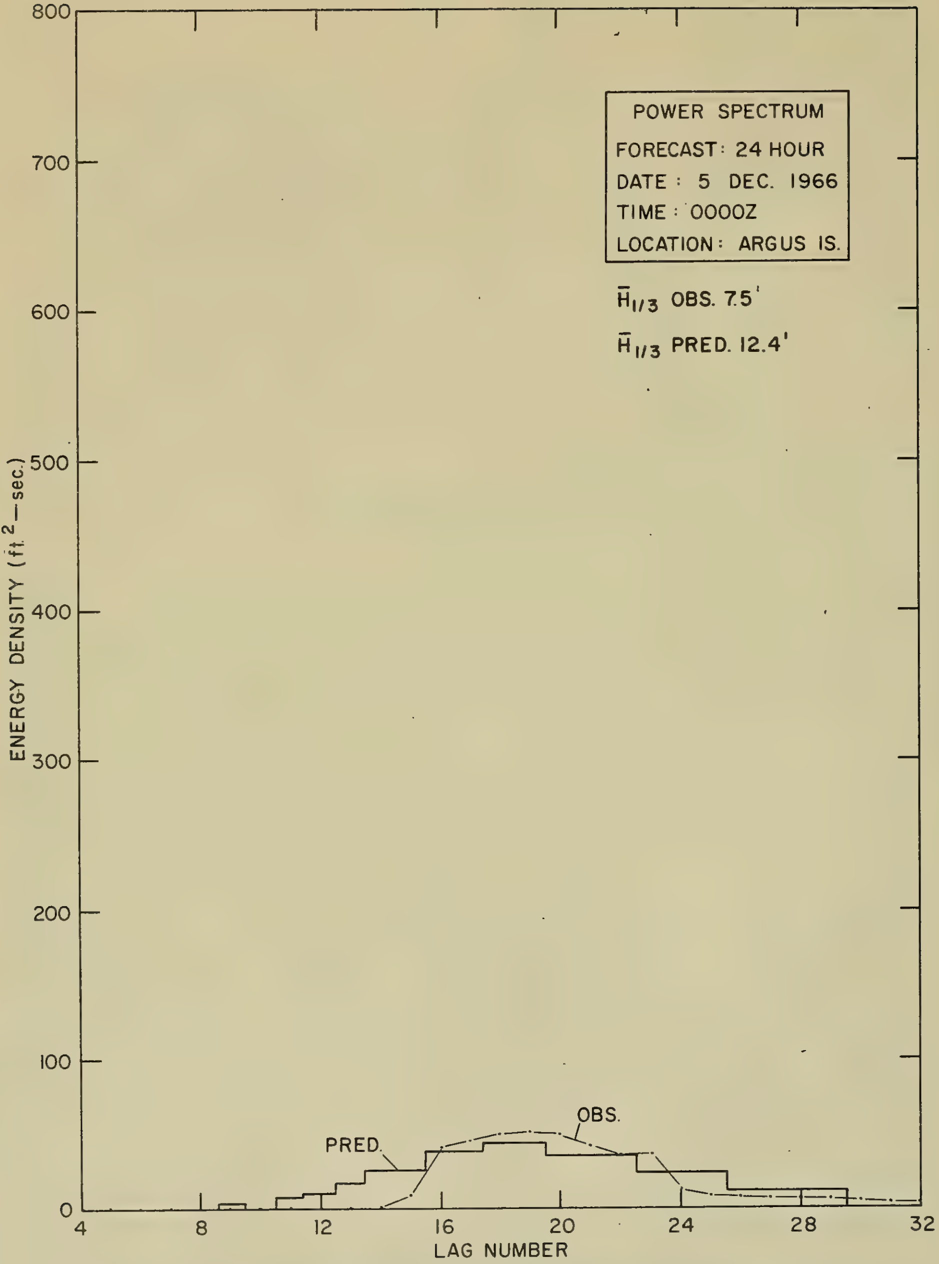

FIGURE 20. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - GREATEST CORRELATION (USWB INPUT).

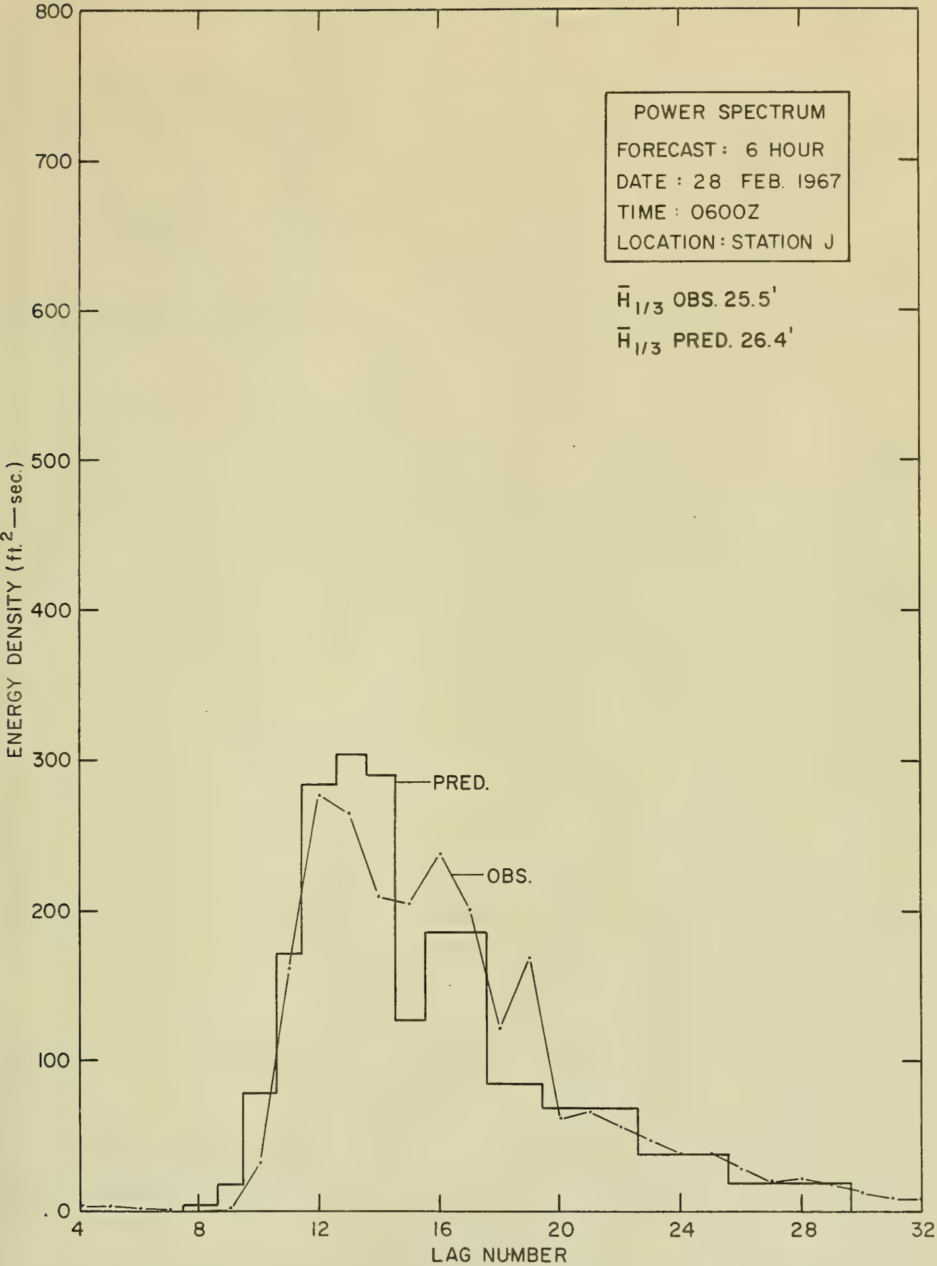

FIGURE 21. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - GREATEST CORRELATION - 6-HOUR FORECAST INTERVAL (FNWF INPUT).

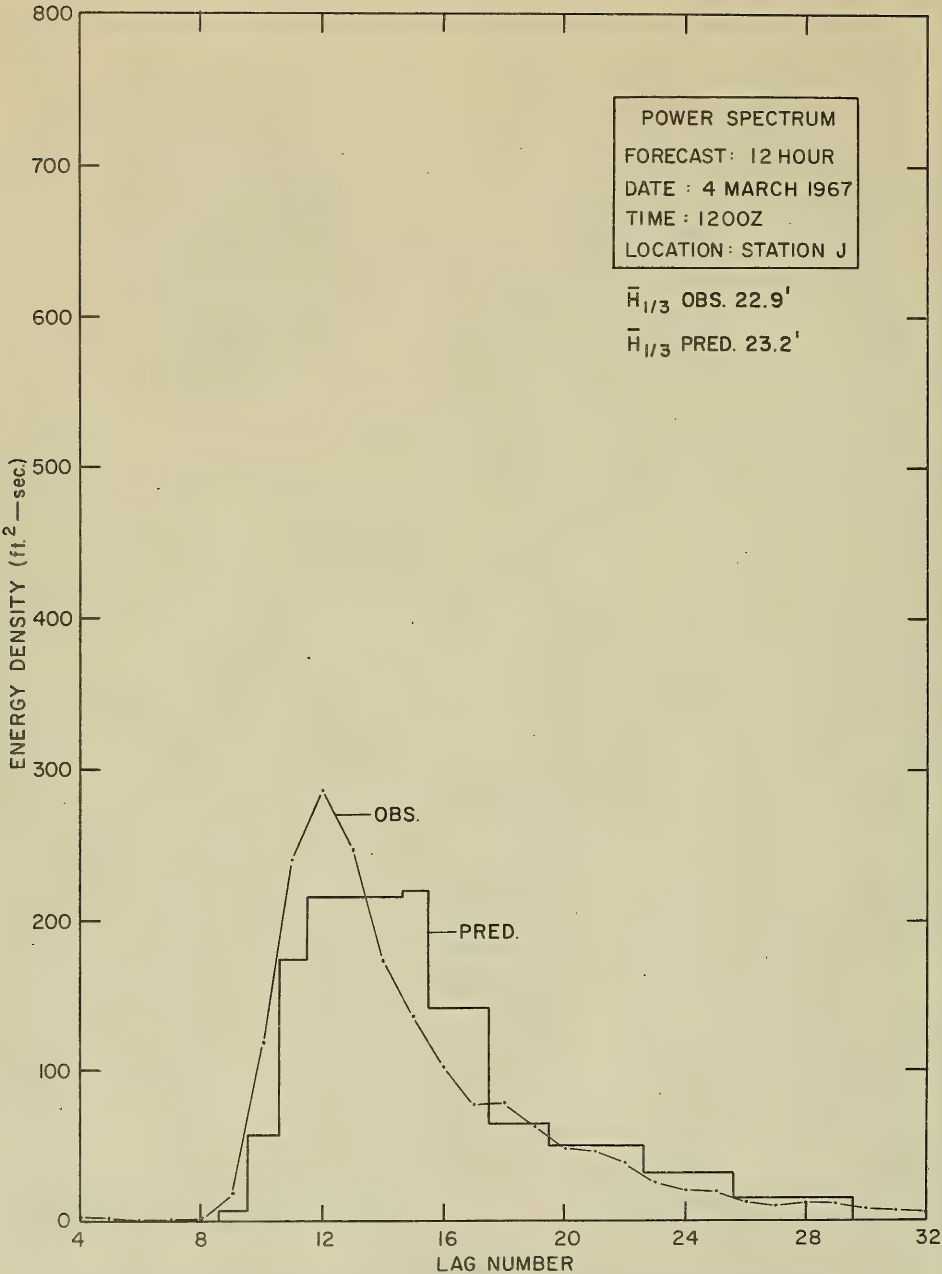

FIGURE 22. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED—GREATEST CORRELATION - 12-HOUR FORECAST INTERVAL (USWB INPUT).

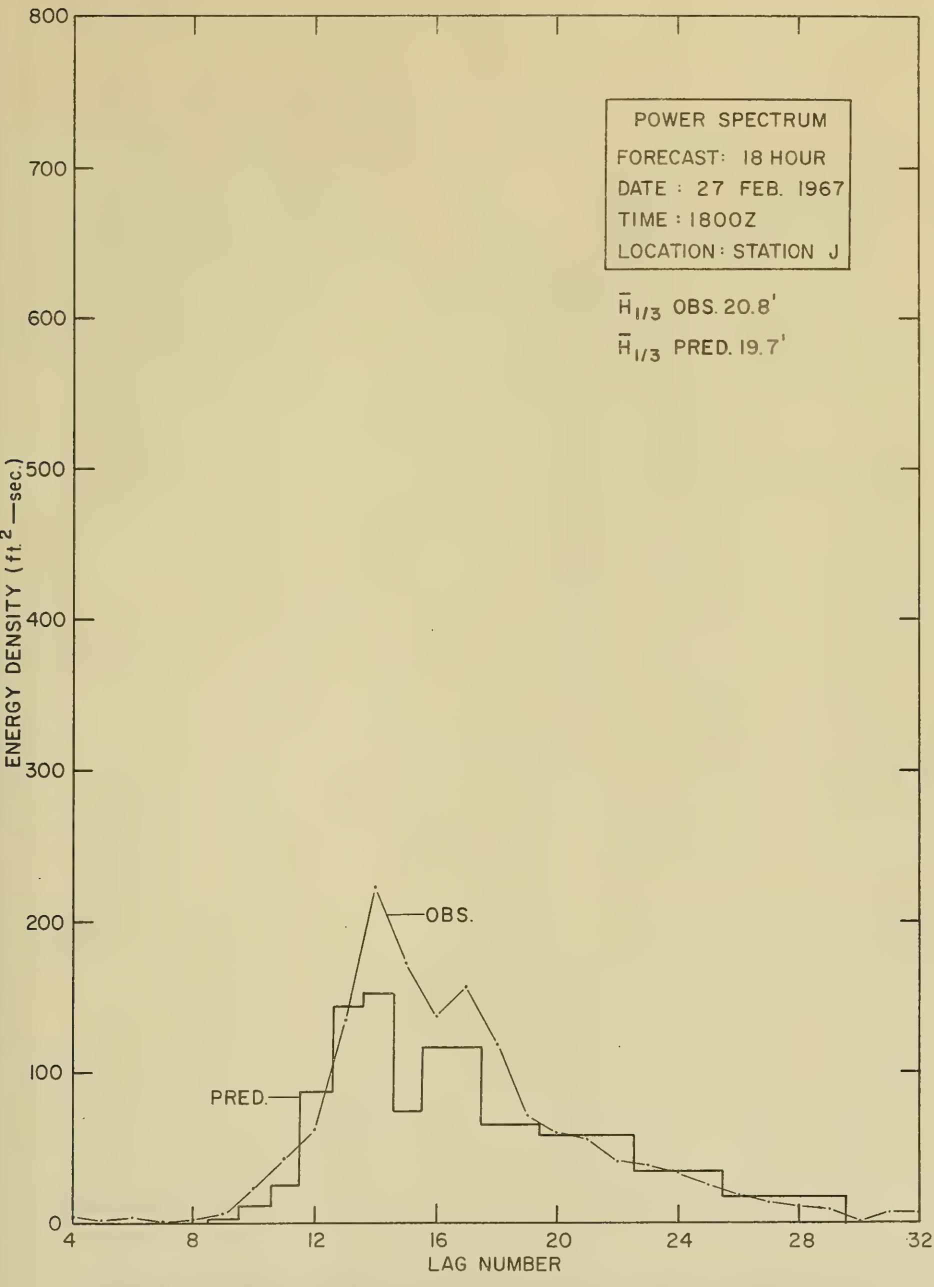

FIGURE 23. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - GREATEST CORRELATION - 18-HOUR FORECAST INTERVAL (FNWF INPUT).

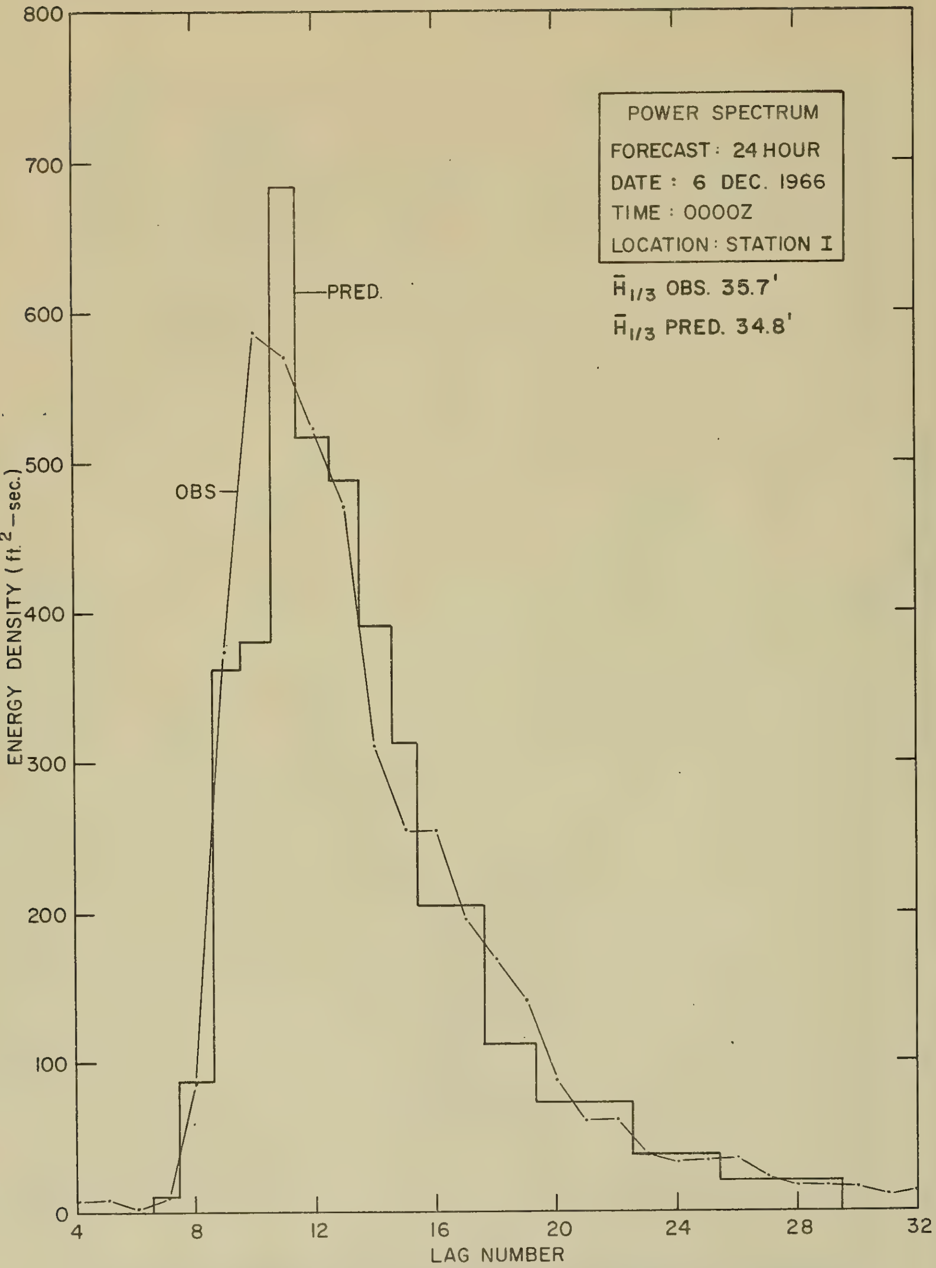

FIGURE 24. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED-GREATEST CORRELATION - 24-HOUR FORECAST INTERVAL (USWB INPUT).

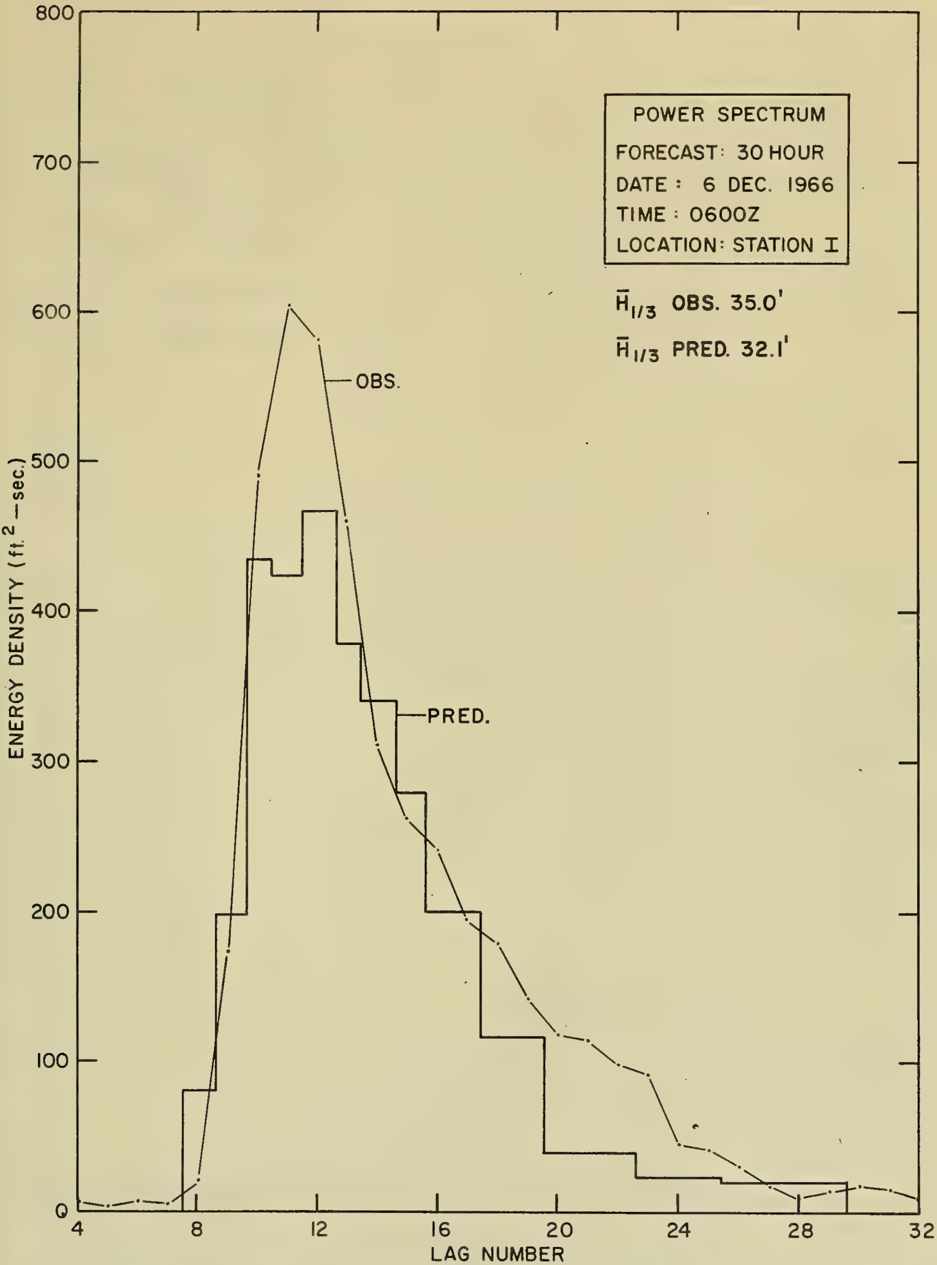

FIGURE 25. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED—GREATEST CORRELATION - 30-HOUR FORECAST INTERVAL (USWB INPUT).

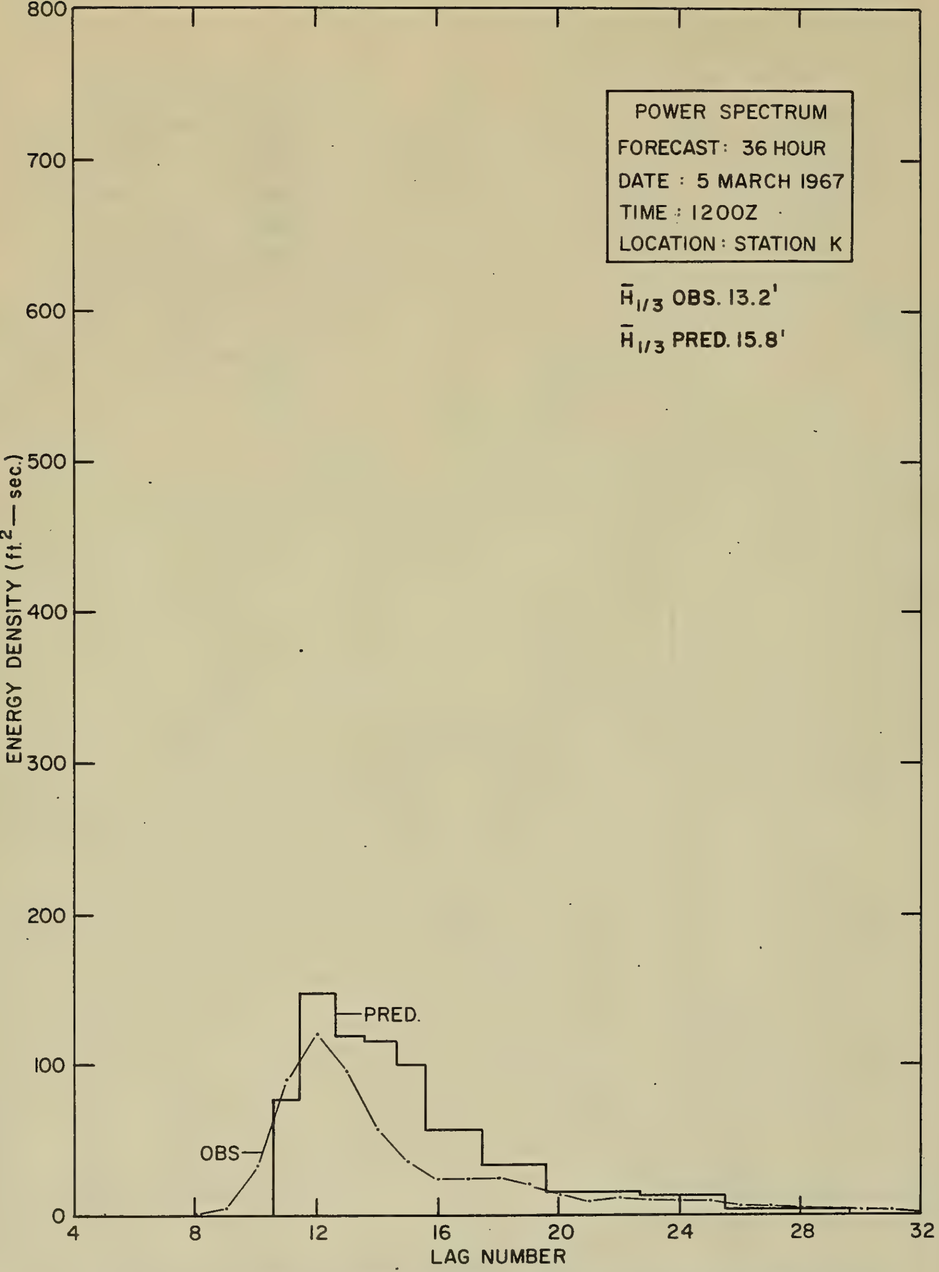

FIGURE 26. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - GREATEST CORRELATION - 36-HOUR FORECAST INTERVAL (USWB INPUT).

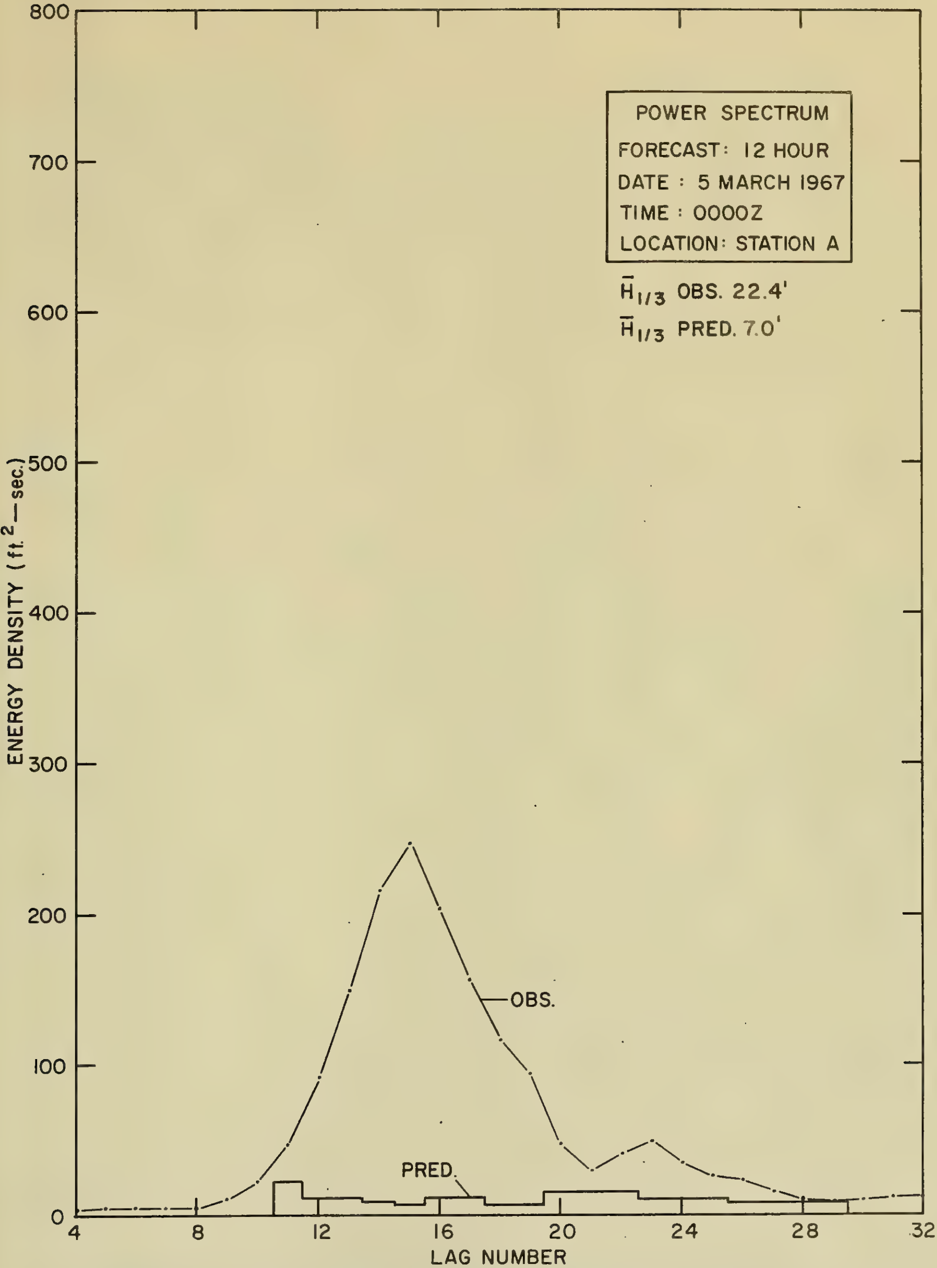

FIGURE 27. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED — LEAST CORRELATION (USWB INPUT).

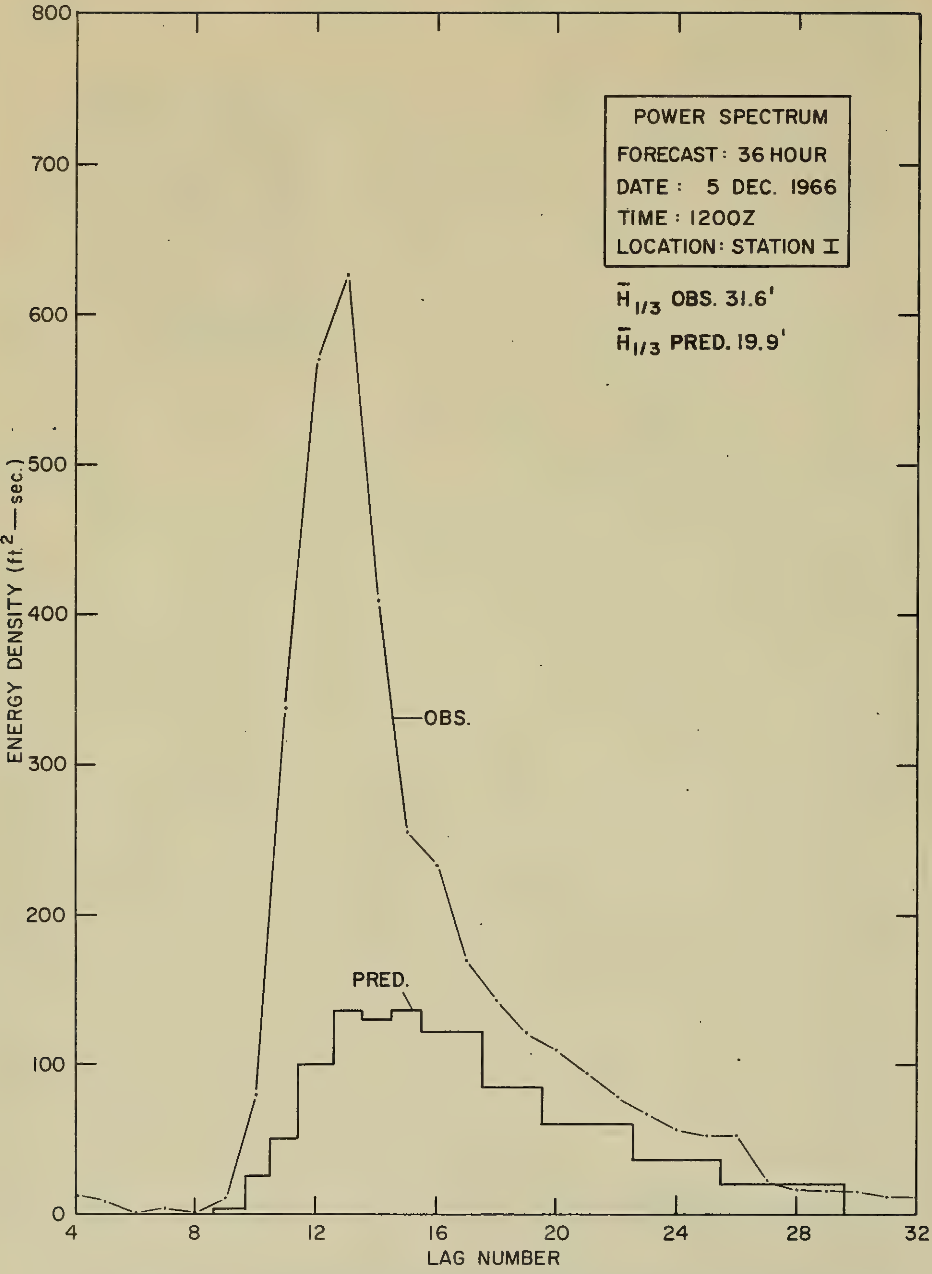

FIGURE 28. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - LEAST CORRELATION (USWB INPUT).

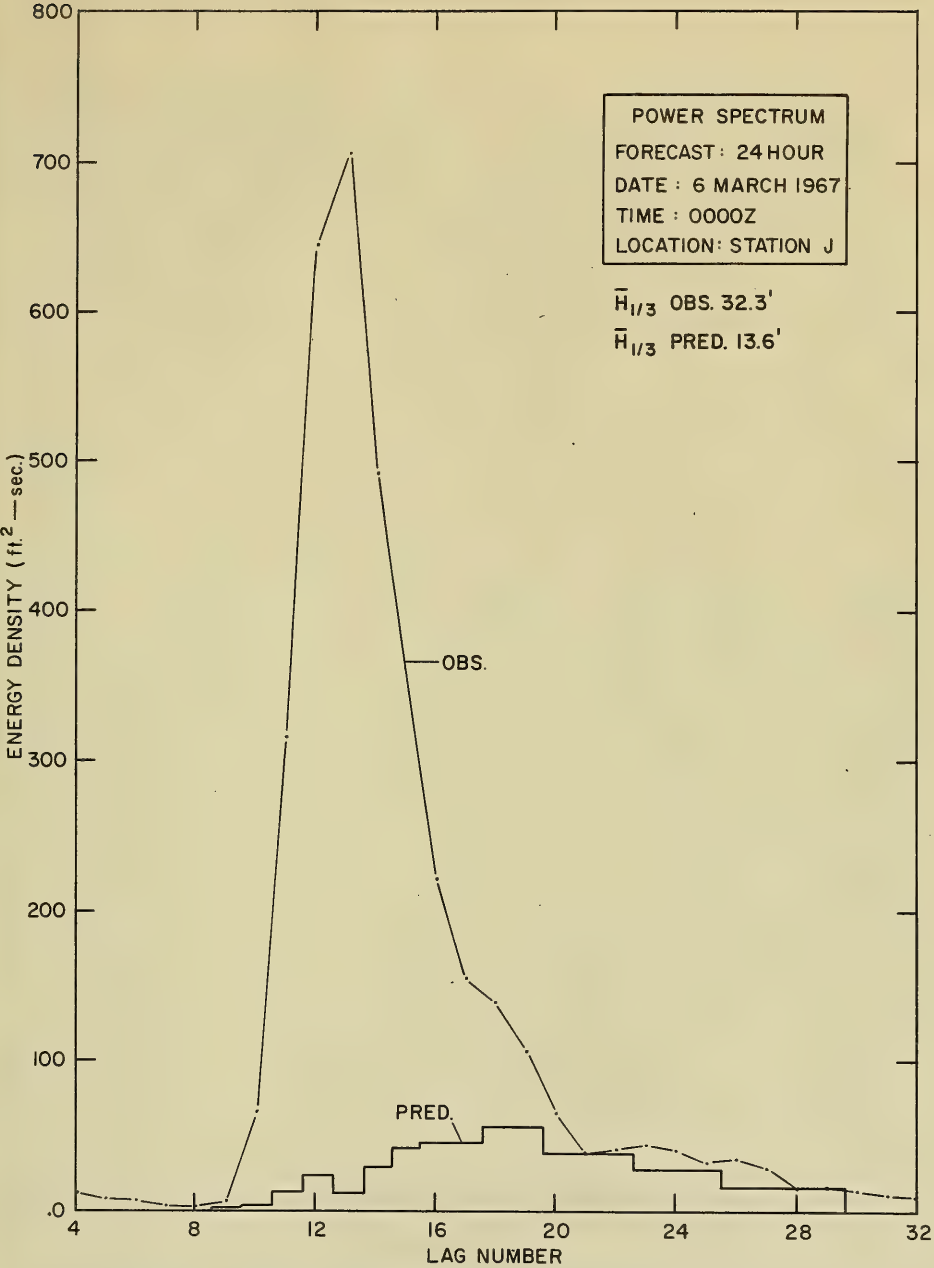

FIGURE 29. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - LEAST CORRELATION (USWB INPUT).

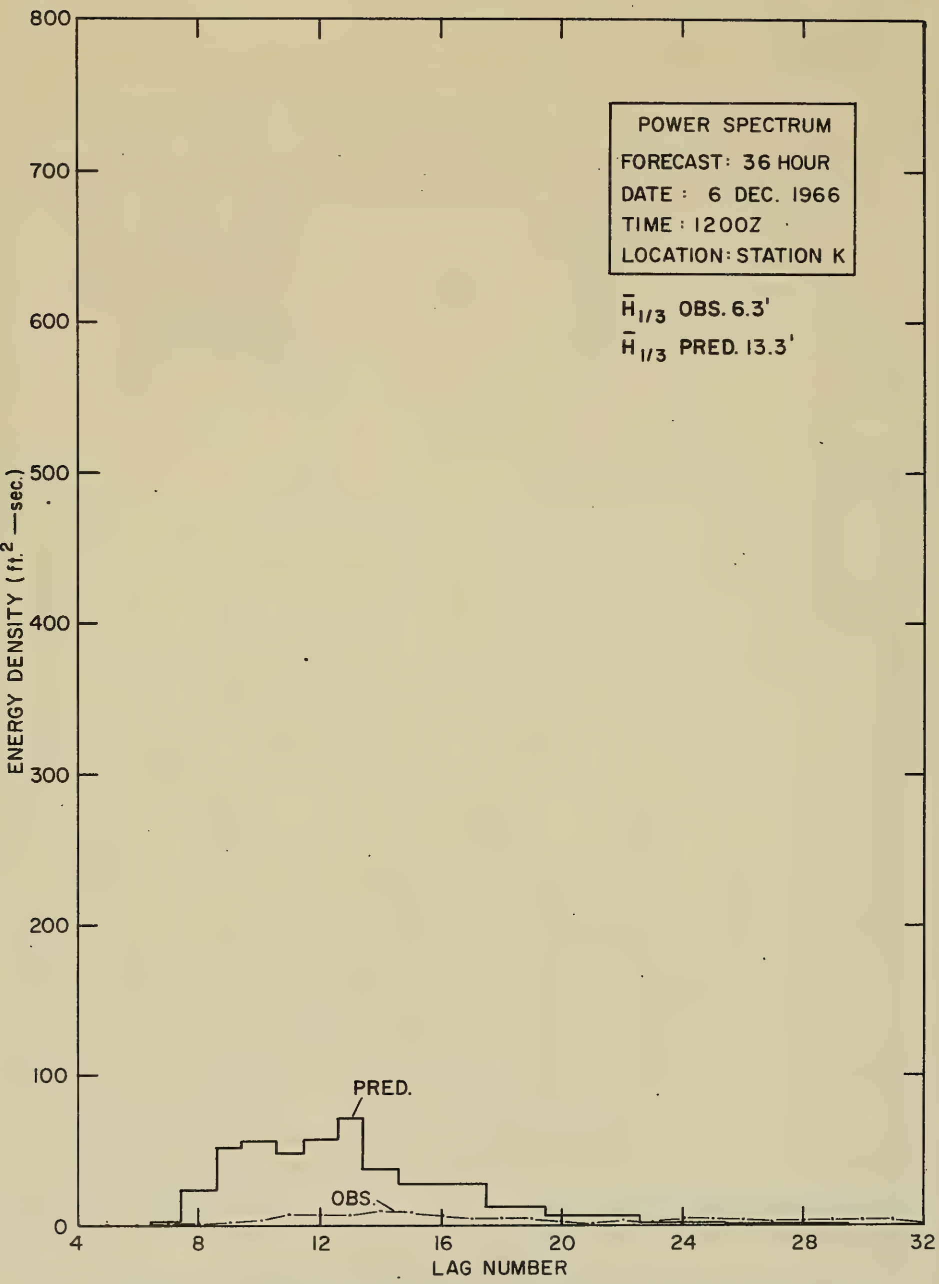

FIGURE 30. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED — LEAST CORRELATION (USWB INPUT).

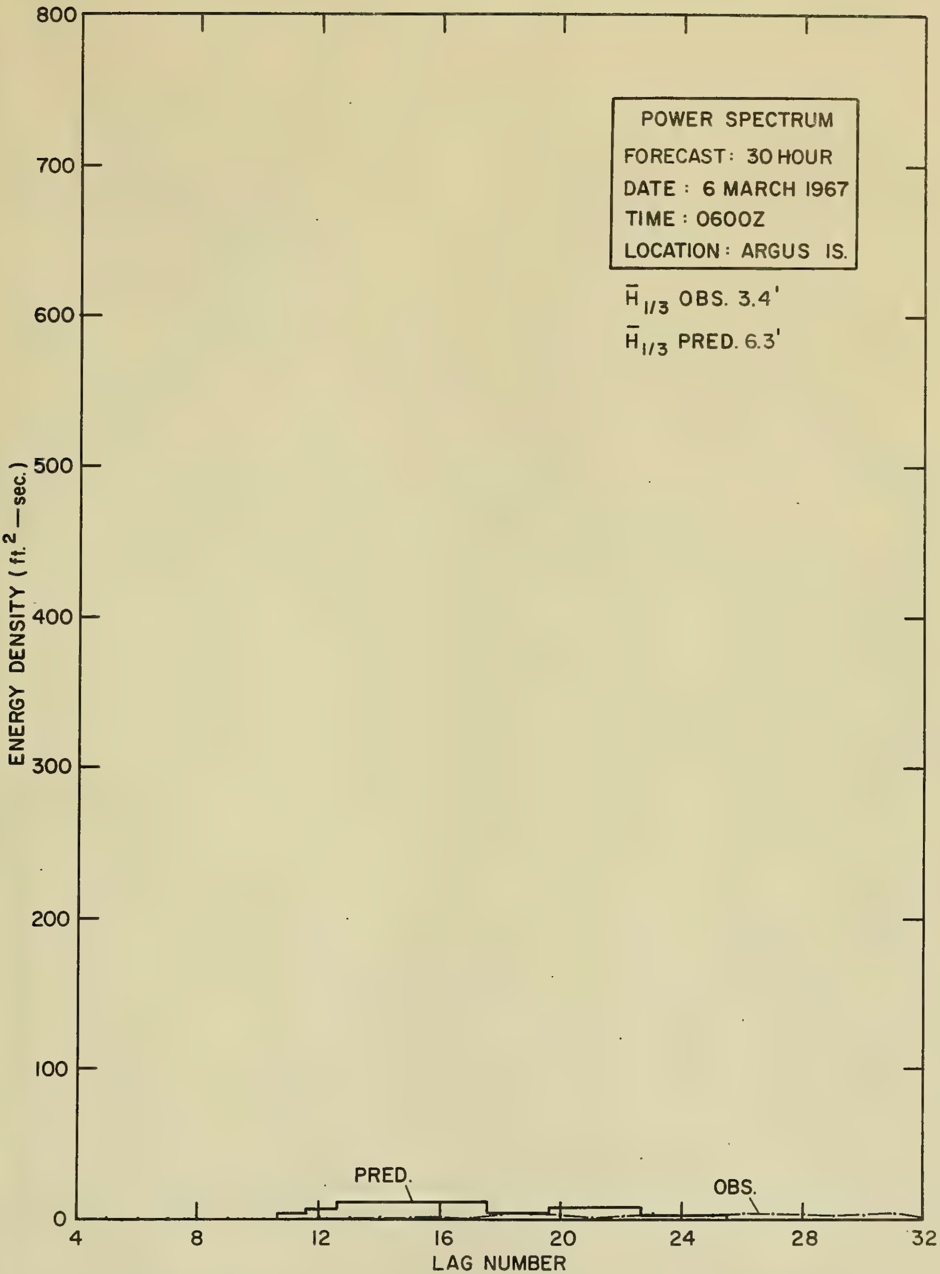

FIGURE 31. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED—LEAST CORRELATION (FNWF INPUT).

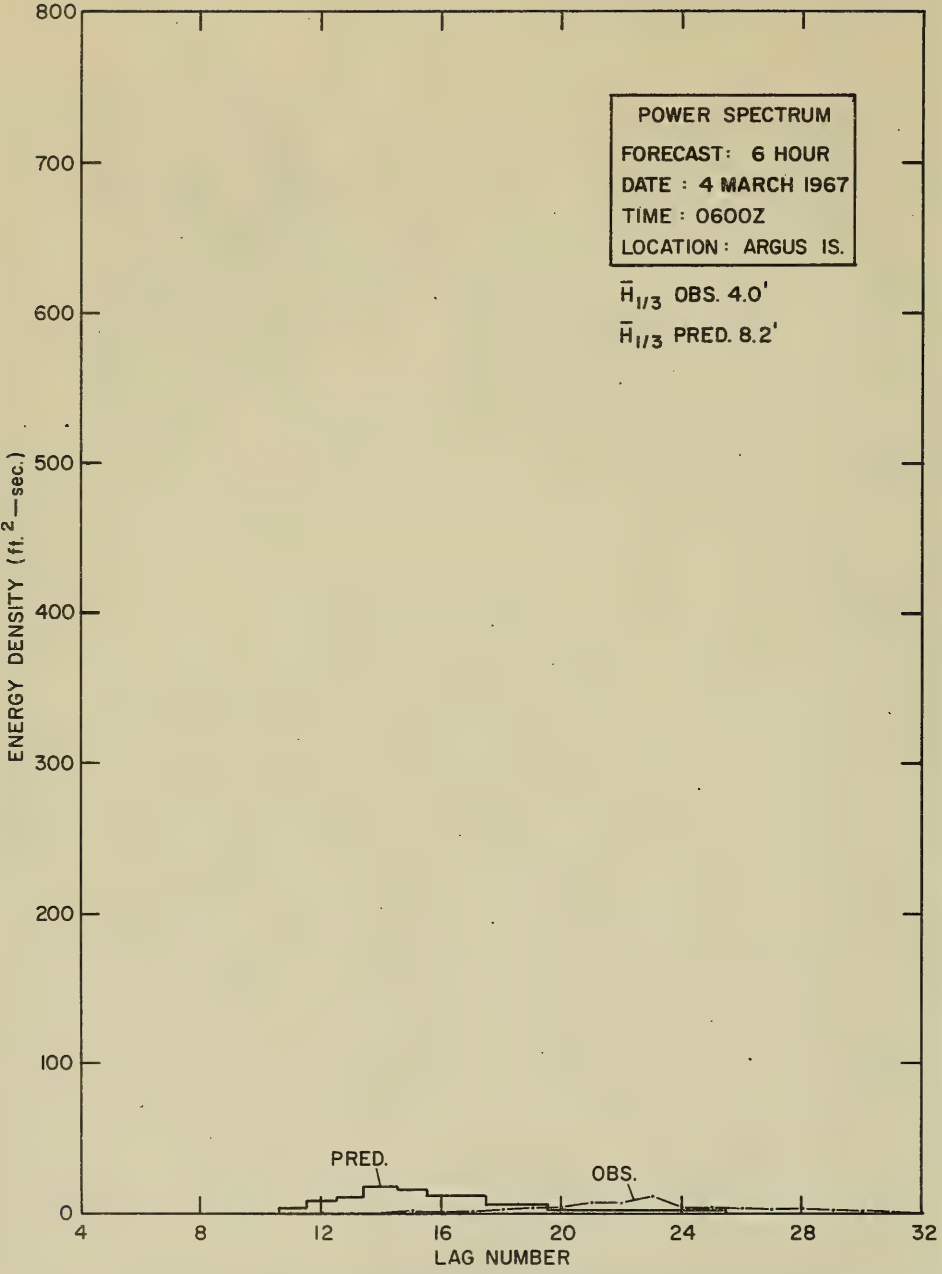

FIGURE 32. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - LEAST CORRELATION - 6-HOUR FORECAST INTERVAL (FNWF INPUT).

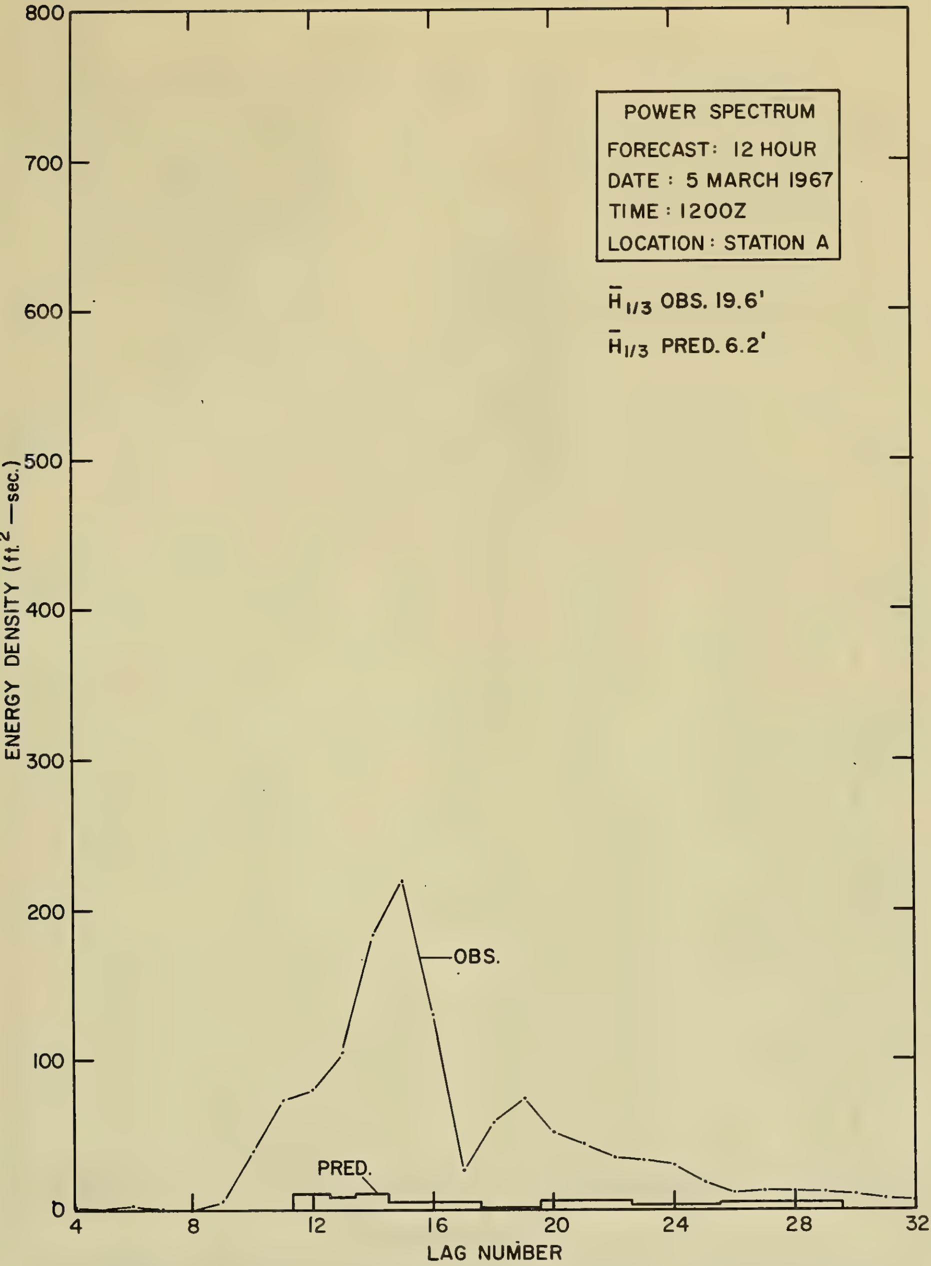

FIGURE 33. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED — LEAST CORRELATION - 12-HOUR FORECAST INTERVAL (USWB INPUT).

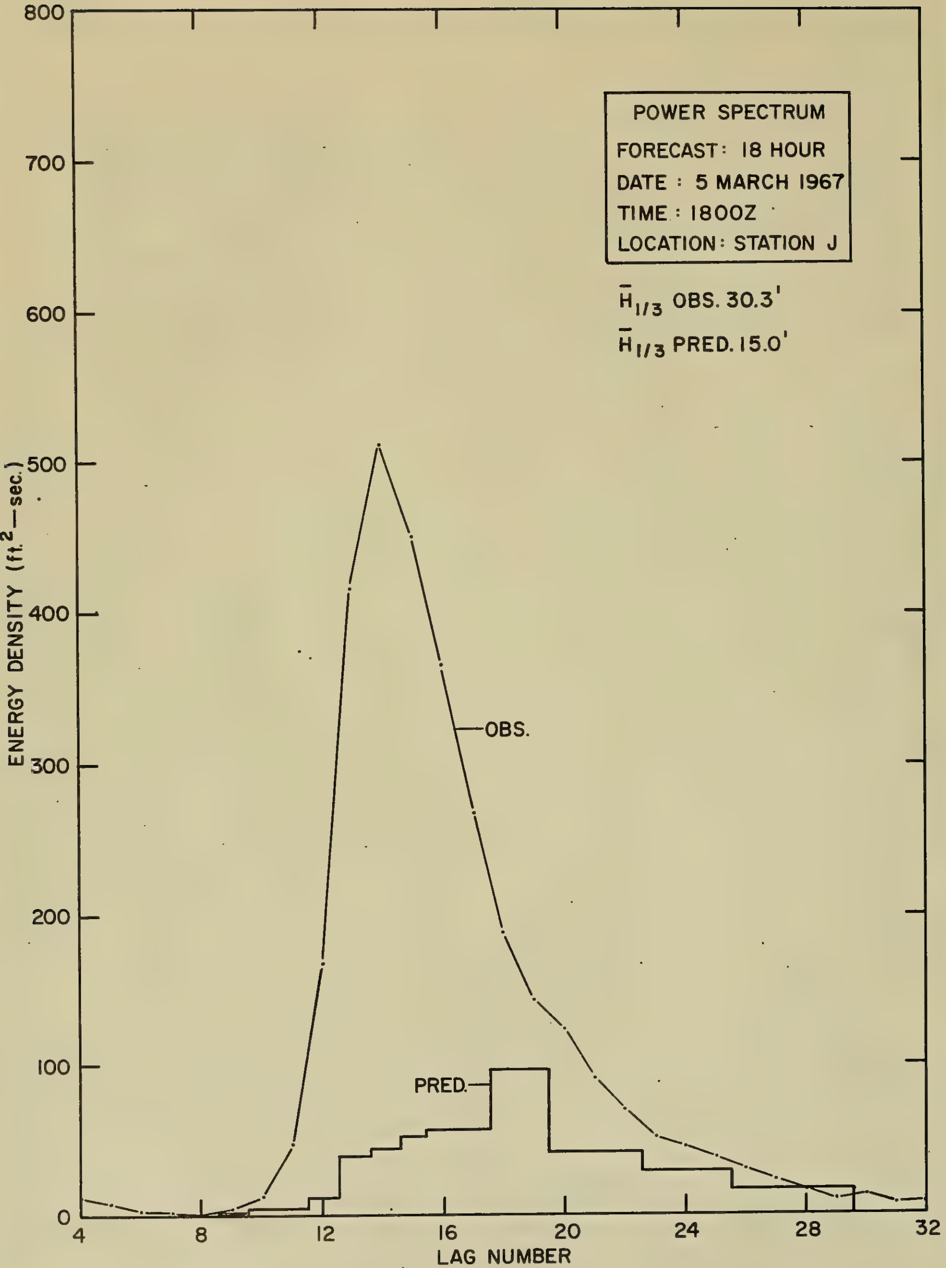

FIGURE 34. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED - LEAST CORRELATION - 18-HOUR FORECAST INTERVAL (USWB INPUT).

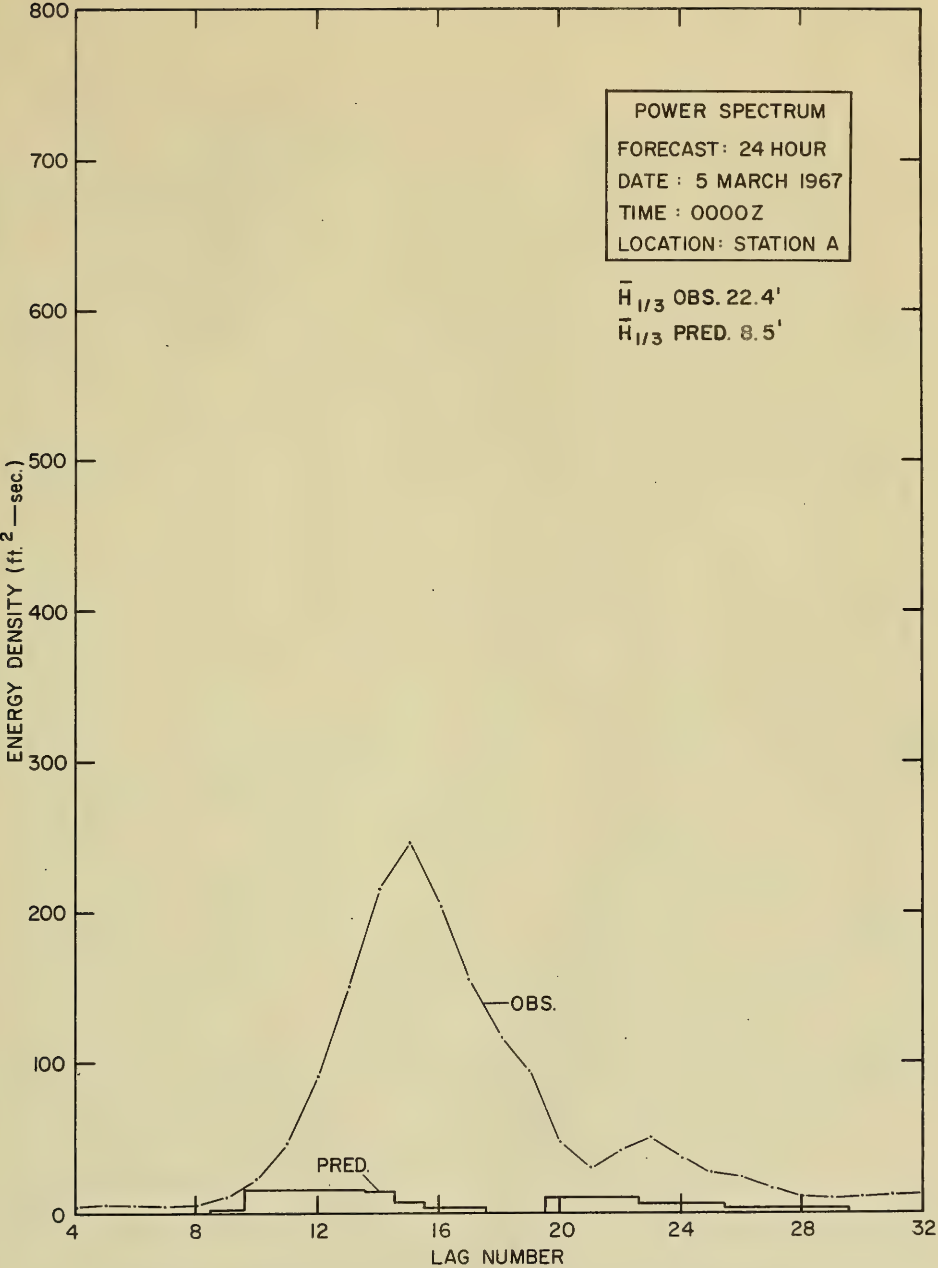

FIGURE 35. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED — LEAST CORRELATION - 24-HOUR FORECAST INTERVAL (FNWF INPUT).

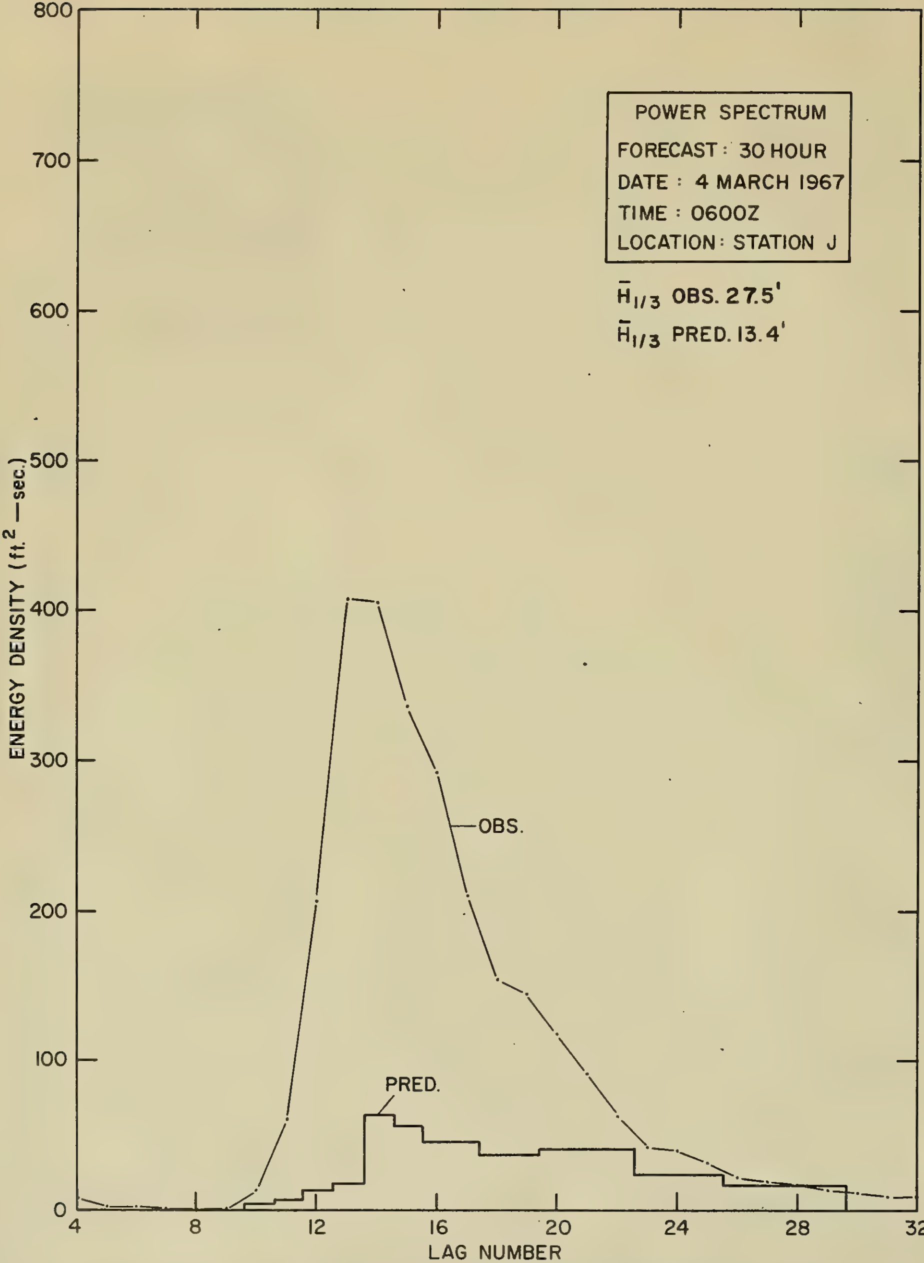

FIGURE 36. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED — LEAST CORRELATION - 30-HOUR FORECAST INTERVAL (USWB INPUT).

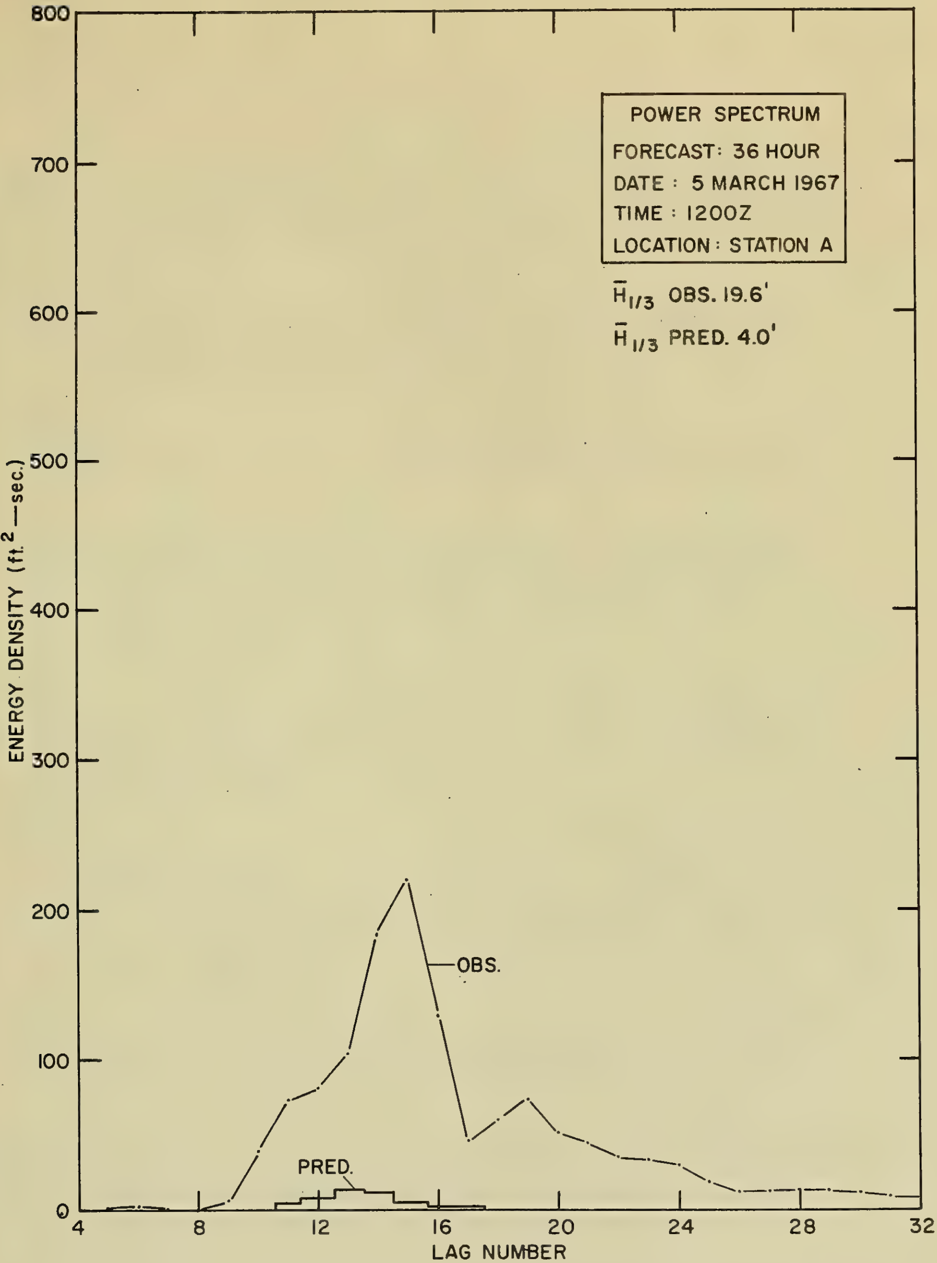

FIGURE 37. WAVE SPECTRA - OBSERVED (MEASURED) VERSUS PREDICTED — LEAST CORRELATION - 36-HOUR FORECAST INTERVAL (USWB INPUT).

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APPENDIX

SYNOPTIC WEATHER CONDITIONS

Period I - 4 December to 6 December 1966 Synoptic Weather Conditions

On the first day there were two frontal systems in the North Atlantic Ocean, one in the western region, which was undergoing frontogenesis, and one in the eastern area, which was dissipating. A low pressure system was undergoing cyclogenesis just off the southeast coast of Greenland with a series of waves along its associated frontal system extending southwestward across Florida. This cyclone developed very rapidly with its center moving northward between Greenland and Iceland to the north of Iceland by 5 December. Gale force winds were reported as far out as 500 miles south from the 956-millibar low pressure center. On the 5th the winds were increasing to whole gale force in the southwestern quadrant as the storm continued to move northward along the Greenland east coast. At this same time a new cyclone was developing on the frontal system about 400 miles east southeast of Cape Sable. This storm was blocked by an anticyclone to the east, however, and did not become of any great consequence. By 1200Z on the 6th, the Greenland storm was beginning to fill, as it reached almost total occlusion. At station I winds reached 46 knots for about 36 hours following the frontal passage and wave heights to 36.4 feet (significant height) were recorded by the wave meter. Very high waves were recorded from 1800Z on the 5th to 1200Z of the 6th. At station K the strongest winds were 18 knots with wave heights to 16.8 feet. Station K remained in the warm sector of the cyclone throughout the period because the cold front never extended this far south.

Period II - 27 February to 28 February 1967 Synoptic Weather Conditions

Early on the 27th a low pressure center, which was rapidly deepening, was moving east northeastward to about 150 miles south of Iceland. By 1200Z on the 27th, the low had deepened to 958 millibars and 60-knot winds were reported. A frontal system extended from the storm center to the south and southwest across the southwestern North Atlantic. As the cyclone center deepened further to 952 millibars and moved northeastward to the east of Iceland, the frontal system moved rapidly eastward to the east of the British Isles by 0000Z of the 28th. The cold front passed over station J between 0600Z and 1200Z on the 27th, but the strongest winds of 43 knots were reported at 1800Z of that day. Wave heights reached their maximum of 31 feet at 0000Z 28 February. Station A was in the northern and western sectors of the cyclone as the low center passed to the south of the station early on the 27th.

Period III - 4 March to 6 March 1967 Synoptic Weather Conditions

On the first day, a cyclone with a 956-millibar center, moving northeastward, was located about 300 miles southwest of Iceland. Whole gale winds extended to 600 miles over most of the southern sector. At the same time a new cyclone was developing about 300 miles southeast of Cape Race, Newfoundland with whole gale winds to 300 miles from the center by early on the 5th. Frontal systems extended southward and southwestward from each of the two cyclones. By 0000Z on the 5th, the low to the southwest of Iceland had moved directly across Iceland in a northeastward direction and began to fill. The new low developing east of Cape Race moved rapidly eastnortheastward passing to the north of the British Isles and into the Norwegian Sea early on the 6th. It did not develop into as intense a cyclone as the more northerly one that crossed Iceland.

From the beginning of the period, station J was in the cold air behind the frontal system associated with the deep low center which later crossed Iceland. At this time J was experiencing winds up to 48 knots, while wave heights reached a maximum about 18 hours later of 29.2 feet. Station A, at the beginning was also experiencing winds of about the same speed but the wave heights did not reach a maximum until 0000Z on the 5th when they were recorded at 22.4 feet. At station K, however, the winds were calm at this time. With the approach of the second cyclone on the 5th, the winds at station J reached a maximum of 55 knots just prior to the passage of the cold front associated with the system. The wave heights recorded at J were as high as 32.3 feet at 0000Z on the 6th. The highest wave heights were also recorded at station K at the same time but they were only 16.5 feet. The strongest winds at K were 27 knots at 1800Z 6 March. As the second storm moved rapidly eastward, the winds at station J died down quickly to 15 knots by 0600Z on the 6th.

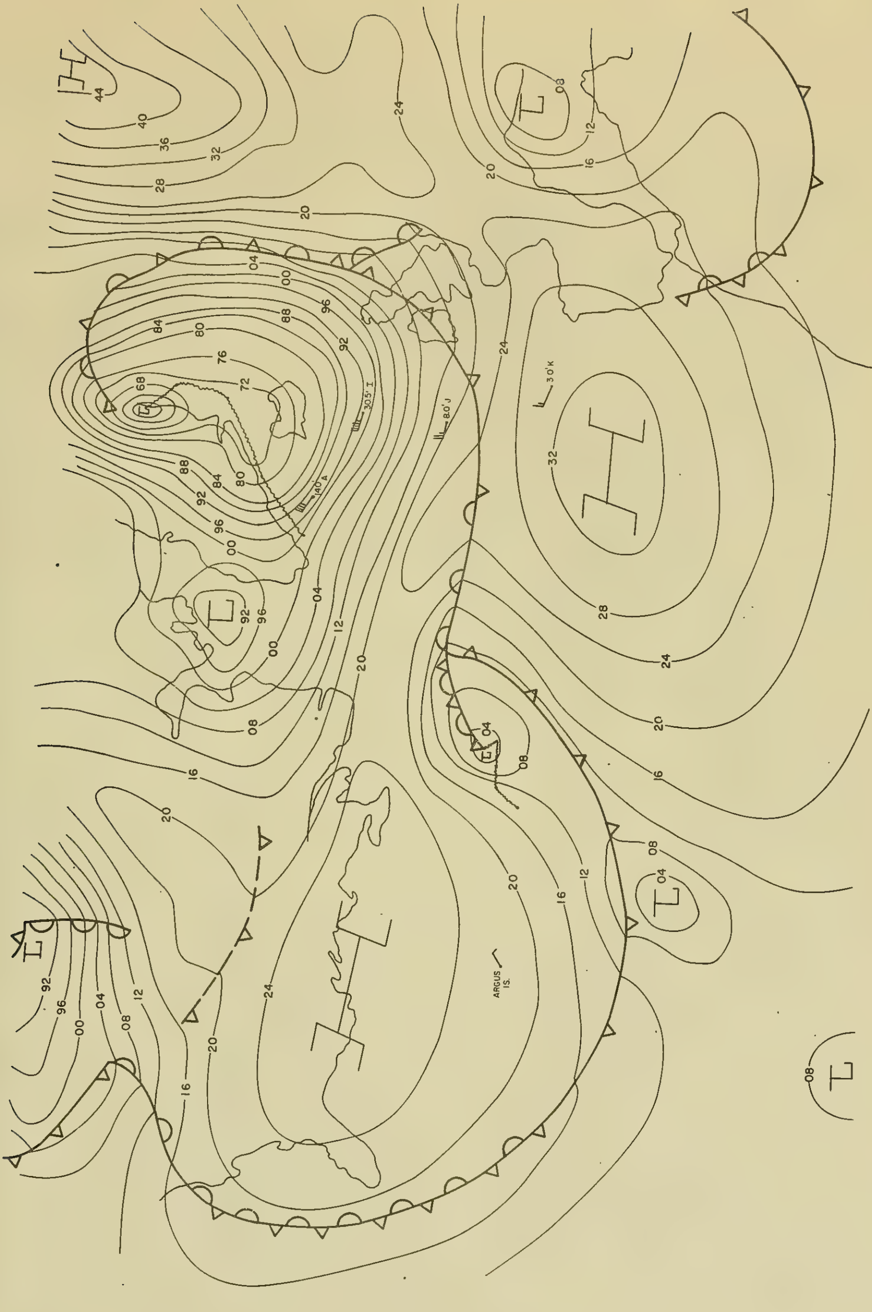

FIGURE A-1. USWB SYNOPTIC SURFACE WEATHER CHART, 6 DECEMBER 1966, 0000Z.

FIGURE A-2. USWB SYNOPTIC SURFACE WEATHER CHART, 28 FEBRUARY 1967, 0000Z.

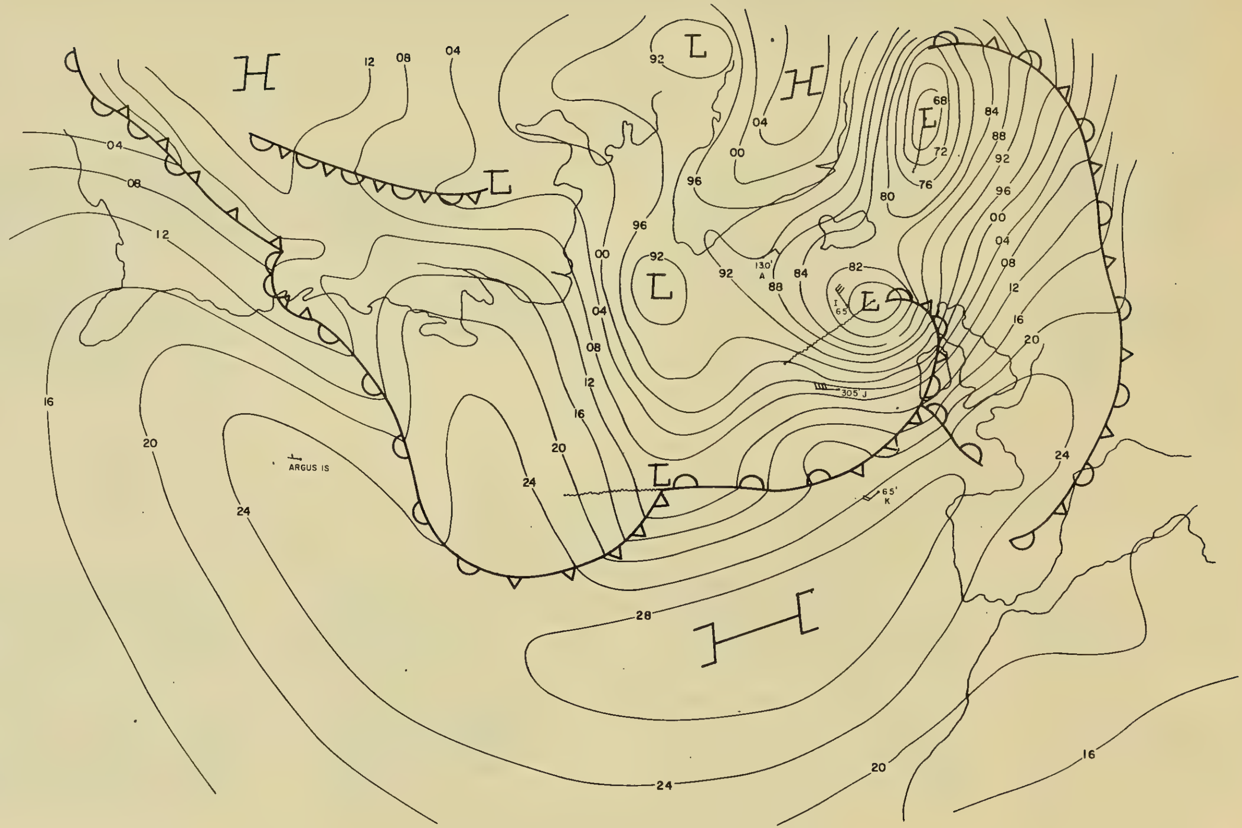

FIGURE A-3. USWB SYNOPTIC SURFACE WEATHER CHART, 6 MARCH 1967, 0000Z.

U. S. Naval Oceanographic Office
AN EVALUATION OF A COMPUTERIZED NUMERICAL WAVE PREDICTION MODEL FOR THE NORTH ATLANTIC OCEAN, by Donald C. Bunting and Lionel I. Moskowitz, July 1970, 66 pages including figures and tables, 8 references (TR-209).

Evaluation of a computerized numerical wave prediction program is described. Statistical analyses were made using wave records from shipborne wave meters and a wave staff. Comparisons are shown between two different sets of real-time input data.

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2. Significant wave height
3. Numerical wave prediction
4. Shipborne wave meter
5. Ocean weather ship
6. Argus Island

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13. ABSTRACT

Procedures used to evaluate a computerized numerical wave prediction program are described. Statistical analyses were made using records from shipborne wave meters or a wave staff at five different locations in the North Atlantic and machine-made predictions of wave spectra for forecast intervals up to 36 hours. Comparisons are shown between two different sets of input data. The results of the evaluation indicate that automated numerical wave spectral predictions are feasible and that the forecasts are within a reasonable degree of accuracy for forecast intervals up to 36 hours.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Significant wave height						
Numerical wave prediction						
Shipborne wave meter						
Ocean weather ship						
Argus Island						

UNCLASSIFIED

Security Classification